METHODS AND TECHNIQUES USED IN THE DEVELOPMENT OF AN EXPERT SYSTEM FOR INSECT SAMPLING PLAN DESIGN.

A THESIS
SUBMITTED FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

LINCOLN UNIVERSITY

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1990

Abstract

An expert systems prototype for insect sampling plan design in the New Zealand apple orchard environment was developed. The prototype advises on the preliminary design, analysis of the preliminary data and the main sampling plan design for insect sampling on apple trees.

A knowledge acquisition technique to overcome the lack of readily available case histories in this field was developed. The technique was used to specify the possible range of problems within insect sampling plan design, by identifying the factors that contribute to a particular design. The range of each factor was determined and used to simulate test cases for preliminary and main sample plan design. The technique is suitable for other areas of knowledge in which the solutions are diagnostic or classificatory.

The statistician-entomologist relationship was investigated by simulating eight advisory-client interactions. Analysis of these showed that statisticians controlled the relationship. The interaction can be characterised by a three-part model: information-collecting, advice-giving, and closing. In three quarters of the interactions the statistician cycled between the information-collecting and advice-giving episodes. The function that this cycling serves is unclear.

Keywords: Expert system, insect sampling plan design, knowledge acquisition technique, advisor-client relationship,

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CHAPTER 1

Introduction

An expert system is a computer program that models expert human reasoning processes by using knowledge extracted from human experts and other sources. Although expert systems were initially developed and used in medicine, industry, geology, chemistry and engineering, they are also useful in natural resource management and agriculture, especially in entomology (Stone et al. 1986). Expert systems in entomology have so far been developed for pest identification and management, and to integrate crop management models.

Design of insect sampling plans is another area where expert systems can be used. Sampling is basic to much of entomological field research and incorporates statistical and entomological knowledge. Statistical expert systems have been developed mainly in the area of data analysis rather than experimental design (Gale 1986). Such systems typically include only statistical knowledge, and not knowledge about the subject area to which they are to be applied.

Sampling plans are used to assess whether and to what extent species occur in certain environments, and to determine the effect of environmental and other factors on species in a biological community. A sampling plan specifies how many samples are to be taken, where the samples should be collected, and the size of the sampling unit. Although sampling is used to acquire data in a form that can be analyzed by existing statistical methods, many entomologists do not have sufficient expertise to design sampling plans without the help of a statistician. Furthermore, statistical knowledge relevant to developing the design of a plan to sample insects is scarce. An expert system in this domain might overcome or help alleviate some of these problems.

Although entomologists are advised to consult statisticians about sampling plan design, they are often reluctant to seek their advice. Reasons for this relunctance are fear of being made to feel ignorant or feelings of inadequacy and intimidation. An expert system may overcome these problems.

Such a system may also help formalize the practical knowledge involved in insect sampling plan design, and assist in modelling a generalized outline of insect sampling plan design for insects in particular environments. At present, entomologists commonly belief that no universal sampling plan for insects exists, but that statistical principles provide some guidance (Southwood 1976).

Expert systems are commonly developed by implementing a succession of prototypes (Hayes-Roth et al. 1983). An expert systems prototype provides an opportunity to test assumptions about the knowledge and the inference strategies of the expert (O'Leary 1988). As in engineering, the purpose of prototyping is to establish whether a product or system can be built and to ascertain if there are any anomalies in the design, thus providing a 'proof of concept'. Prototyping is also used in the design of information systems (Earl 1979) and decision support systems (Henderson and Ingraham 1982).

Knowledge acquisition is the process of eliciting knowledge from the expert, interpreting this knowledge in order to infer the expert's underlying reasoning processes, and finally constructing a model that describes the expert's knowledge and performance (Kidd 1987).

The underlying assumption of most techniques used for knowledge acquisition is that test cases of various types are available to the knowledge engineer (Harmon and King 1985). However, many application areas for expert systems exist for which a suitable array of test cases is not available. Design of insect sampling plans is in this category. While insect sampling plans form much of the basis of entomological research, they are not the primary objective of the research. Hence they are not reported in the literature to the same extent and level of detail as the primary objectives of the research.

Expert systems developers have traditionally concentrated on capturing an expert's problem-solving behaviour, but in practice an interaction between an expert and a client often occurs. While most expert systems are supposed to simulate this interaction, few systems achieve this objective. A step towards development of an expert system that models both the problem-solving behaviour of the expert and the interaction between expert and client, is a thorough understanding of the structure and content of the expert-client relationship. Because few reports are available on observational procedures to capture the communicative behaviour between experts and clients (but see Coombs and Alty 1980, Belkin 1987), suitable techniques for this purpose need to be developed.

The objectives of this study were:

1. To investigate the interaction between statistician and entomologist and develop a model of their communicative behaviour.

2. To implement a prototype expert system for insect sampling plan design..

The study is organized as follows:

- Chapter 2 provides an overview of expert systems in general, and expert systems developed in entomology and statistics in particular.
- Chapter 3 discusses the knowledge acquisition methods used in the development of a prototype expert system for insect sampling plan design.
- Chapter 4 reports on an empirical study on the advisory interactions between statisticians and entomologists.
- Chapter 5 describes a prototype expert system for insect sampling plan design in the apple orchard environment.
- Chapter 6 discusses the findings of the previous chapters.
- The prototype is available on disk in the back of this thesis.

Research in this thesis published prior to submission includes:

Senjen, R. (1988). Knowledge acquisition techniques used in the development of an expert system for insect sampling plan design. Proceedings of the Third New Zealand Conference on Expert Systems, Wellington p.178-190.

Senjen, R. (1989). Knowledge acquisition by experiment: developing test cases for an expert system. AI Applications in Natural Resource Management 2(2): 52-55.

Chapter 2

Expert systems: an overview

2.1 Introduction

Expert systems is a branch of artificial intelligence (AI). The development of the first expert system in the early 1970's marked a paradigm shift in AI thinking. Instead of modelling human thinking in terms of general problem solving strategies and heuristic search techniques, emphasis shifted towards knowledge-based modelling of expertise in a narrow field or domain (Forsyth and Naylor 1986). This branch of AI became known as expert systems.

Dendral and MYCIN were two of the first expert systems developed. Dendral uses mass spectral data to deduce molecular structures (Buchanan and Feigenbaum 1978), whereas MYCIN advises physicians on therapies for infectious diseases (Shortliffe 1976). Although significant in a historical sense, both systems were of little practical importance. On the other hand, XCON, an expert system that configures VAX systems for Digital Equipment Corporation, was one of the first commercially-successful expert systems. The system reportedly saved the company millions of dollars annually (Fulton 1987).

By 1988 the number of commercially-used expert systems was estimated at 1400, and 8500 more systems were under development (Reddy 1988). At first commercial systems were developed for industries that promised high returns (e.g., the oil and computer industries). The next wave of development occurred in the military and consumer-industrial area. Many systems were developed to perform activities such as equipment fault diagnosis and data interpretation (Rauch-Hindin 1986). Expert systems in use today include such diverse applications as monitoring data during liquid oxygen tank processing, diagnosing faults in plastic injection moulding, and authorizing and screening credit requests (Reddy 1988). On a generic level, expert systems have been built to model the following human tasks: interpretation, prediction, design, monitoring, planning, debugging, repair, instruction and control. (Hayes-Roth et. al 1983).

The purpose of this chapter is to give a brief synopsis of expert systems technology and some of its problem areas. Expert systems developed in entomology and statistics are reviewed.

2.2 Expert systems technology and some of its limitations

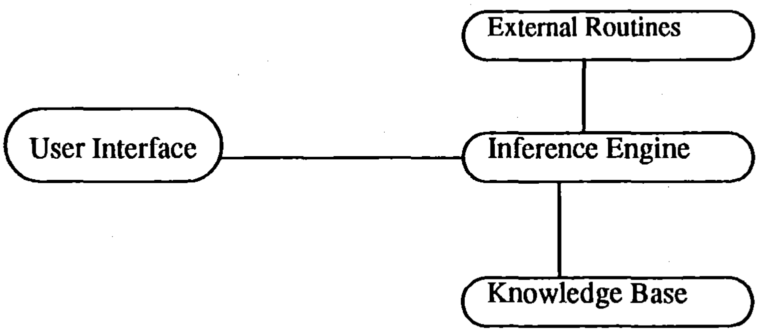
2.2.1 Expert systems components

Generally expert systems consist of a user interface, an inference engine and a knowledge base (Figure 2.1). External subroutines (e.g., simulation models, data base managers, and communications programs) may be integrated to enhance the power and versatility of the system (Stone et al. 1986).

The inference engine controls the reasoning processes used by the program. It determines and controls the sequence of logical steps that will lead to the resolution of the problem by using the information contained in the knowledge base and the output from the supporting external subroutines. Information is obtained from the user via the user-interface.

The knowledge base commonly contains facts, opinions, and heuristics (rules of thumb) specific to the domain (i.e., the domain is the field of knowledge to be modelled). The expert system is usually developed with the assistance of at least one human domain expert. The knowledge in the knowledge-base may be stored in numerous ways. Most commonly, it is stored as rules (an if-then statement), and sometimes as frames (a nested list that stores information about the attributes of and relationships between objects), semantic networks (objects stored as the nodes of branching networks with the interconnections defining the relationships), tables or a combination of these (Stone et al. 1986).

Figure 2.1: General structure of a rule-based expert system. Key elements are the inference engine, knowledge base and user interface. External subroutines may be present to enhance power and versatility of the system (adapted from Coulson and Saunders 1987).



2.2.2 The use of prototyping as a method for developing expert systems

(a) The prototype concept

Prototyping has become an accepted expert systems development methodology (Hayes-Roth et. al 1983) and consists of a cycle of inplementation and testing until the system displays the expected behaviour (Buchanan et. al 1983). However little agreement can be found in the literature on the different types of prototype , and the relationship between a prototype and a fully fledged system is.

The purpose of a prototype is to establish if a system can be built and to ascertain if there are any anomalies in the design, thus showing that the system is in principal possible. This is similar to it's use in engineering. An early definition of an expert systems prototype is provided by Harmon and King (1985): an initial version of an expert system, with 25 to 200 rules, that is developed to test the effectiveness of the overall knowledge representation and inference strategies being employed to solve a particular problem. This definition omits any reference to the importance of the user interface design, a topic of increasing interest to researchers.

Kahn and Bauer (1989) distinguished functional, design and implementation prototypes. A functional prototype emphasizes a demonstration of capabilities, rather than a design that is sufficient to implement all the desired objectives. The purpose of the functional prototype is to elicit systems requirements by showing the user how the finished system will look and feel. A design prototype explores possible solutions and provides a means to develop design specifications. Finally an implementation prototype signals a partially complete system, in the sense that additional refinement is directed towards knowledge-base expansion, rather than design changes.

Distinguishing between an implementation prototype and earlier prototypes appears reasonable. Making a distinction between a functional and a design prototype, however, seems quite impractical in the context of expert systems development, as any prototype preceding the implementation prototype will contain elements of function and design.

Other authors refer to a prototype as a mock-up initial version (Budde and Sylla 1984) or scale model (Weiser 1982), without distinguishing between the different purposes a prototype can fulfill. Sometimes a distinction is made between a rapid first prototype (Stock 1987) and subsequent prototypes. A rapid prototype is a small system developed early in a project and used as a discussion point for further interviews with the expert and for systems development. It can be thrown-away, if the focus or structure or the implementation language is judged inappropriate.

In summary, a prototype is an earlier version of a system. It is often used to elicit further knowledge from the expert and to establish user requirements. The objective of prototyping is to clarify characteristics and operations of a system by constructing a version that can be exercised. A prototype encourages discussion between expert and developer and allows the developer to experiment with ideas for implementing the system (Bratko 1989).

(b) Prototyping as part of expert systems development

Expert systems development relies largely on empirical methods, rather than a general methodology (Guida and Tasso 1989). Nevertheless several proposals have been reported in the literature that discuss the role of prototyping in the development of expert systems.

Harmon and King (1985) described the building of an expert system as a sequence of six phases:

1. Selection of a problem.
2. Development of a prototype.
3. Development of a complete system.
4. Evaluation of the system.
5. Integration of the system.
6. Maintenance of the system.

This is similar to Guida and Tasso (1989) proposed expert systems life cycle:

Phase 1 - Plausibility study.

Phase 2 - Demonstration prototype construction.

Phase 3 - Full prototype construction.

Phase 4 - Target systems implementation.

Phase 5 - Operation, maintenance and extension.

The purpose of prototyping is not to arrive at a final configuration of the system, but to establish that the representation of the expert's knowledge and the strategy used for solving the problem is adequate for the task (Harmon and King 1985). While it may be helpful to divide expert systems development into stages on a conceptual level, in reality the phases of expert systems development are not likely to be so clear cut. Iterative refinement in each phase must be carried out until the prototype reaches a satisfactory performance in terms of the goals of each phase. Iteration might occur between phases, and the later phases of development may never be reached.

Evaluation of the prototype consists of one or more demonstrations to the expert and users and testing of the prototypes with realistic data. Guida and Tasso (1989) gave no indication at which stage the system should be evaluated in a more formal sense (especially for knowledge verification, i.e., is it in agreement with expert judgement). Presumably formal evaluation occurs, similar to the proposal by Harmon and King (1985), when the system is thought to cover the problem area sufficiently. When this point is reached depends largely on the confidence the systems developer has in the system and the knowledge extracted from the expert.

Authors generally disagree on when a system should be formally evaluated. Some suggest formal evaluation should occur after the final system has been developed (Harmon and King 1985), others (Buchanan et. al 1983) advise evaluation after a full prototype has been constructed, because then the evaluation can seriously contribute to systems development.

There seems to be no explicit rule that indicates to developers when a prototype becomes a full system. Once the need for clarification of systems requirements has ceased, and any additional refinement of the system is directed towards knowledge-base expansion, the prototype is in the process of transforming into a fully fledged system. At this point the prototype itself may be thrown-away (e.g., the prototype is reimplemented in another language) or it may simply be expanded into the full system.

2.2.3 Expert systems limitations

Although the development of expert systems is a profitable industry, limitations to their success have become clear. Practical expert system applications seem at present limited to domains that are narrow in scope, do not require common sense or world knowledge or sophisticated natural language understanding. Difficulties in transfering this new technolology and evaluating expert systems are further limiting their success.

Areas in which expert systems have been most successful are science and engineering, or in domains comprising codified knowledge (e.g., Government standards). Basden (1983) termed these fields of knowledge 'deep and narrow', in the sense that any increase in expertise in these fields is obtained by finer tuning and the inclusion of more special-case reasoning. He contended that fields of knowledge that are 'wide and shallow' are more difficult to model in an expert system, as they may include a wide range of potentially relevant factors, may lack expert consensus, and may require common sense or world knowledge. Difficulties in modelling common sense behaviour have been cited by critics of AI in general (see Dreyfus and Dreyfus 1986) as proof that modelling human intelligence is impossible.

Developers give too little consideration to the problem that expert systems (like all models) are selective, based on assumptions and prone to failure (Clancey 1989). The currently favoured prototyping approach for expert system development has a number of limitations:

- Although a prototype may work, it may not be a very good representation of the expertise and the problem solving strategies that the expert used (Winston 1984).
- In order to get a working model, certain simplifications must be made and the prototype may be representative of only a small portion of the problem-solving capabilities of the expert.
- The problem may have been stated too narrowly, and the resulting system may not be important or may not solve the problem of interest (Haugeland as cited by O'Leary 1988).
- The prototype may include a researcher bias.
- The prototype solutions may be inappropriate, incomplete, or suboptimal (O'Leary 1988).

However in comparision with other approaches (e.g., top-down systems design) prototyping also offers a number of advantages. For instance prototyping allows for easy updating to accomadate changed neddds (Basili and Turner 1975), development of the software is gradual and low-risk , and early delivery of initial versions of the system facilitates communication between developer and user (Ince 1988).

Dialogue capabilities permitting a two-way flow of conversation and a choice of dialogue level have been recognized in the early 1980s as important future capabilities of expert systems (Pollack et al. 1982). Such features would require internal models of user goals and expectations, and the system would need extensive natural language capabilities.

An often-cited advantage of rule-based expert systems is their ability to explain their reasoning at virtually any point in an interaction with the user (Stock 1987). What is really meant by this statement is that rule-based expert systems can display the rules used to solve a particular problem. This is not usually helpful to a user, nor does it provide an explanation of the causal reasoning behind the use of particular rules.

Early in the development of expert systems, several systems were constructed that were never used. Weiss and Kulikowski (1984) cited the example of CASNET, an expert system advising on the diagnosis and treatment of glaucoma. While the system was judged to have reached clinical proficiency, it was never used because no real demand existed for it. Lack of demand was partly a problem of technology transfer. At the time of systems development doctors were still apprehensive about the use of computers, and additionally they were not really consulted during the system's development. Potential users and their goals need to be considered to make this technology more than an academic exercise. Successful expert systems design involves not only the use of sophisticated programming techniques, but also input from psychologists and sociologists (Stock 1987).

2.3. Review of expert systems in entomology and statistics

2.3.1 Expert systems in entomology

(a) Introduction

Applied entomology can be viewed as a subset of natural resource management. Expert systems in natural resource management have seen a rapid increase over the past five years. Davis and Clark (1989) provided a selective but comprehensive bibliography of expert systems papers in this field. In a partial survey, Lambert and Wood (1989) reported that 76 expert systems are under development or in use. A quarter of these systems concerned crop production, or pest management or livestock production. The remainder was concerned with financial analysis, marketing, natural resource and fire management.

Entomological expert systems fall largely into three categories: identification of insects, management of insect pests, and integration of crop management models. One of the few commercially available expert systems is 'Counsellor', an expert system for cereal disease and pest recognition in winter wheat. 'Counsellor' is available on video-text (Norton 1989). However, many expert systems in agriculture and entomology are fully developed (e.g., by the US Department of Agriculture), but are in-house products or are not yet commercially available (Stock 1990).

(b) Expert systems for the identification of insect pests

Conceptually, expert systems for insect pest identification are diagnostic expert systems. Diagnostic systems require an item to be classified or a choice to be made between options (Noble 1987).

Traditionally, hierarchical decision keys have been used to solve diagnostic problems. A decision key is an arrangement of distinguishing features of a taxonomic group to serve as a guide for establishing relationships and names of unidentified members of that group. Many diagnostic expert systems still rely on decision keys, but these are not necessarily hierarchical. Expert systems are also easier to modify then paper-based decision aids or conventional conputer programs, and ways of dealing with uncertain and incomplete data can be incorporated (Schmoldt and Martin 1986).

Diagnostic problems are usually well defined; once a cooperative expert has been found, these systems are quite straightforward to design and implement (Stone et al. 1986). Typical examples of this approach in entomology are SYSTEX and PREDICT. SYSTEX is a systematics expert system, that aids in the identification of the genus Signiphora (Stone et al. 1986). It is still under development. PREDICT is a system that helps foresters diagnose pest problems in red pine (Schmoldt and Martin 1986). This system is in the field testing stage. Both systems are rule-based.

Kemp et al.(1989) reported on a system under development that will diagnose pests, diseases and disorders in apple crops. The system has the dual aim of supplying diagnostic advice to apple growers and teaching students how to identify pests, diseases and disorders of apples. However, Clancey (1983) warned that rule-based systems cannot easily be adapted to serve two different goals because teaching and problem-solving cannot easily be modelled at the same time.

(c) Expert systems for the management of insect pests

Pest management expert systems are similar to insect pest identification systems in the sense that the problem solving process they model is diagnostic. Rather than identifying a particular pest, they advise on how to deal with the pest once it is identified. Kemp et al. (1988) described an expert system for rangeland grasshopper treatment selection. This rule-based expert system was developed to use site-specific environmental user input; it is now in use, and provides the user with appropriate treatment selections and a cost/benefit ratio.

POMME (Roach et al. 1989) is a an expert system under development to aid apple orchard management. The prototype advises on spray scheduling, treatment of winter injuries, drought control and insect problems. POMME deals with each of these problems as separate entities, and is therefore not very different from the systems previously described. However, it does incorporate external information such as weather data and disease forecasts.

(d) Expert systems to integrate crop/pest management models

The development of the concepts of integrated pest management and simulation modelling in the past two decades has resulted in many potentially useful agricultural and horticultural decision aids and models. However, delivery of these models and decision aids in a useful form has been problematic. One major reason has been the difficulty of transferring the information needed to operate and interpret these models to a user who is not an expert.

In the case of a single model, Stone et al. (1986) suggested that expert systems can act as intelligent interfaces and provide rules for the interpretation of the model's output and predictions. When several models are integrated, expert systems can act as agents for interpretation which call upon the different models as necessary.

An example of an expert system to repackage a simulation model is COMAX (Lemmon 1986). This expert system includes GOSSYM, a cotton crop simulation model. The model predicts crop growth and yield in response to external weather variables, soil physical parameters, soil fertility, pest damage and the practical knowledge of extension specialists. The expert system manages data input and interprets the model output. The purpose of the system is to maximize cotton yields while minimizing inputs to the cropping system. The system is designed to run continuously throughout the crop year on a dedicated microcomputer. Preliminary tests, during the field testing stage, performed on one large cotton farm have demonstrated excellent results in reducing the unit cost of production.

COTFLEX (Coulson et al. 1987) is an expert system that incorporates a number of simulation models (i.e., pest development and interaction, economic models for price forecasting, and farm financial analysis based on current farm policy) to describe and simulate a farm in the Southern Blacklands, Texas. Unlike the systems described previously different knowledge representations are combined, permitting more specialized search and conflict resolution strategies. Knowledge can be represented at a deeper, causative level (Coulson et al. 1987), perhaps leading to a system that can explain its own reasoning. COTFLEX has reached field testing stage. Other systems that integrate simulation models with expert systems technology are SIRATAC (Hearn 1987), POMME and CALEX (Coulson et al. 1987).

Ultimately, use of expert systems in conjunction with simulation and management models has limitations. Simulation and management of natural systems are very broad problems and often cannot be captured easily in an expert system because they may involve extensive use of natural language processing, spatial reasoning, common sense, or all of these factors. Expert systems technology is presently most successful in domains that are clearly defined and quite narrow in scope.

2.3.2. Expert systems in statistics

(a) Introduction

As early as 1977, Nelder (1977) pointed to the need for packages that not only analysed data, but also advised the user about the correctness of his/her choice of data model and analysis. Early research on expert systems in statistics concentrated on development of these types of systems (see Gale 1986 for a review of early systems). Early statistical expert systems either aid the user in selecting appropriate statistical analysis or guide the user in the application of these methods once they have been chosen.

(b) What makes statistical expert systems different ?

Statistics, and hence statistical expert systems, differ from systems for other speciality areas in at least two ways. Unlike other domains, the statistician has knowledge about statistics, but usually limited knowledge about the problem domain. This poses special problems for the designer of such systems. The incorporation of meaningful dialogue rather then one-way interactions between the expert system and the user becomes paramount.

Much statistical consultation requires the statistician to ask questions about the subject matter and to clarify the problem. The statistician must be able to do this for many different subject-matter areas and to recognize unusual or unexpected circumstance or both, including those never encountered before (Oldford and Peters 1986). Modelling this type of interaction may involve incorporation of a level of natural language understanding and world knowledge that is not feasible at the present level of technology.

(c) Necessary requirements for a successful statistical expert system

Hand (1984) suggested that statistical consulting is similar to diagnostic consulting. Statistical expert systems should be based on a process of hypothesis generation and verification, similar to those of medical diagnosis systems.

Features that should be included in such a system can be divided into functions the systems should perform (e.g., design of statistical studies, selection of statistical strategies and data analysis) and ability to serve different types of users. Features of such a system include the usual ones (such as easy modification, presenting questions in intelligent order, provision of multiple answers and explanation), but also more domain-specific features such as multiple transformation of data, selection of techniques adapted to the data, allowing for mistakes by naive users and selection of the most appropriate statistical technique (Hand 1985). Incorporating all these functions and features into one system would be a mammoth effort. Hand's (1985) discussion lacks specific solutions to these problems and resembles more a wish-list for an all-purpose system. Experience in other areas has clearly shown that successful expert systems solve problems in narrow, well-defined domains.

What seems most important is to design systems, especially in the data analysis field, that can decide whether or not a proposed analysis is meaningful or that can interpret the results of an analysis in a meaningful way to the user (Wittkowski 1986). At present, providing expert analysis once a class of model or a type of data analysis has been selected seems to be the most realistic and successful approach to the problem.

(d) Examples of statistical expert systems

Several expert systems have been built for data analysis. For example, REX (Prebigon et al. 1984), is an expert system to provide guidance, interpretation and instruction for regression analysis. The system reached the demonstration stage, but actual use has not been reported in the literature.

Other examples of expert systems for data analysis include a system to aid in multivariate analysis (Smith et al. 1983), GUHA-80 (Hajek and Ivanek 1982) - a system to generate hypotheses for exploratory data analysis and BUMP (Hand 1988), an intelligent interface to MULTIVARIATE (a data analysis package).

Gottinger (1988) reported on Xsample, an expert system that advises on the appropriate analysis of the univariate two-sample location problem. Xsample is an example of an expert system that advises the user about what statistical tool to choose for a particular problem.

Wittowski (1988) warned that expert systems technology has not been readily accepted in those areas of statistics that have been explored and that most systems were built for research only, rather than distribution. An exception is CADEMO (Rasch et al. 1988), an expert system that provides computer-aided design of experiments and modelling. It is commercially available and includes all stages of statistical advice beginning with the precise formulation of the problem and ending with the interpretation of the results. CADEMO was designed for a user with some knowledge of statistics, and can be used on a personal computer (it is written in Fortran 77).. While the system appears to guide the user through the various stages of statistical analysis, it does not prevent 'errors of the third kind' (Kimball 1957), i.e., giving the right answer to the wrong question.

Chapter 3

Knowledge Acquisition Methods to develop a Prototype Expert System for Insect Sampling Plan Design

3.1 Introduction

Knowledge acquisition is the process of extracting knowledge from the expert, so that it can be encoded into a suitable knowledge representation. Kidd (1987) described this process, which consists of three steps, in more detail:

1. Use of a technique to elicit data (usually verbal) from the expert.
2. Interpretation of the verbal data (more or less skillfully) to infer what might be the expert's underlying knowledge and reasoning process.
3. Use of this interpretation to guide the construction of some model or language that describes (more or less accurately) the expert's knowledge and performance.

While methods for describing the expert's knowledge (commonly called knowledge representation) are frequently reported in contemporary AI literature, advice on how to gather and interpret this knowledge is still sparse (the so called 'knowledge acquisition bottle-neck'). Techniques developed for knowledge acquisition from human experts include analysis of verbal protocols (e.g., Ericsson and Simon 1980, Waldron 1985), knowledge acquisition grids (Lafrance 1987), question probes (Gordon and Gill 1989), neurolinguistic programming (e.g., Evanson 1988), several methods from cognitive psychology (Hoffman 1987), and general methods of questioning and analyzing interviews (Hart 1987). After analyzing a sample of real-world expert system applications Cullen and Bryman (1988) reported that a combination of different techniques is commonly necessary to produce a working expert system.

Knowledge may also be gathered from other sources such as journals, books, manuals, databases and case studies. Knowledge from these sources is often used in the initial phase of knowledge acquisition and to familiarize the knowledge engineer with the domain, but can in fact be used at any stage during the expert systems development. Knowledge gathered in this way rarely contains the heuristics, intuitive hunches and experiences commonly used by human experts to solve problems (Garg-Janardan and Salvendy 1987).

Knowledge can be viewed as declarative or procedural (Gordon 1989). Declarative knowledge is knowledge of what we know about objects, events and relationships between concepts. This type of knowledge is relatively static and can be represented in semantic or propositional networks or both (Norman and Rumelhardt 1975, Anderson 1983). Declarative knowledge can include a type of procedural knowledge, i.e., knowledge about the proper sequence of steps used to perform a task or to solve a problem (Gordon 1989).

Procedural knowledge is knowledge about how to actually perform a task (i.e., a person might be able to describe the sequence of steps involved in riding a bicycle - declarative knowledge, but for this person to actually be able to ride the bicycle requires procedural knowledge). It is relatively non-verbal, generally inaccessible to introspection (Anderson 1983) and is used with little awareness (Gordon 1989). Experts seem to use this type of knowledge under normal, everyday conditions with familiar problems (Newell and Simon 1972), but they use declarative knowledge in new and unusual situations. In an expert system, knowledge about the proper sequence of steps used to perform a task or solve a problem is captured in rules, while declarative knowledge can be used to provide explanations of why knowledge is used in a particular way. Most existing expert systems utilize only use the first type of knowledge, even when 'explaining' their reasoning.

This distinction between procedural and declarative knowledge is in a psychological rather than computer science sense. In computer science, the terms procedural and declarative have a somewhat more restricted meaning. Declarative knowledge describes classes and relations, while procedural knowledge is expressed in rules and control structures (Alty and Coombs 1984). Declarative is sometimes equated with logic and Prolog is the typical declarative language. Third generation languages are generally viewed as procedural.

The availability of test cases or data is an underlying assumption of many knowledge acquisition techniques. Test cases can be actual case histories, or case histories can be used to create hypothetical test cases (e.g., case histories can be altered to withhold information, change information or produce entirely new cases).

This chapter describes the process of knowledge acquisition and the techniques used in developing prototype expert systems for insect sampling plan design. A 'rapid' prototype and a demonstration prototype were implemented, and the description of knowledge acquisition methods used and knowledge obtained to construct these prototypes are reported in separate sections. The term 'rapid' prototype refers to a prototype that is developed early in the knowledge acquisition process. It is shown to the expert to help generate cooperation, discussion, feedback etc. The 'demonstration' prototype is closer to the finished product, in that it contains a vertical slice of the decision tree (i.e., the depth rather than the breath of a problem is explored).

3.2 Review of commonly-used knowledge acquisition techniques

3.2.1 Introduction

The literature on knowledge acquisition falls into several categories:

1. Actual methods for eliciting knowledge from an expert, such as interviewing methods, task analysis, psychometric techniques and general methodologies (e.g., Gordon 1989).
2. Advice on how to manage the interpersonal relationship with the expert (e.g., Evanson 1988).
3. Articles predominantly concerned with knowledge representation, i.e., how to turn the knowledge elicited into expert systems programs.

The scope of this review section does not include articles on knowledge representation or relationship management, nor does it discuss automatic knowledge acquisition in any detail. Instead the author concentrates on the review and evaluation of person-person knowledge acquisition methods. In automatic knowledge acquisition, the knowledge engineer is replaced by a machine that, for example, directs the expert through a series of tasks (e.g., listing concepts, sorting concepts) (Cooke and MacDonald 1986) or uses induction to acquire the desired knowledge.

The author follows Lafrance (1987), who states that person-person knowledge acquisition is the most routinely-used and broadly useful method of acquiring expertise. Person-person knowledge acquisition can be applied in any domain and may eventually provide directions on how expertise transfer can be automated. Although the different person-person knowledge acquisition methods are discussed separately, a combination of these methods is often used in practice.

3.2.2 Interviews

(a) Introduction

Interviews play a dominant role in knowledge acquisition for expert systems and are an integral part of some knowledge acquisition methodologies (e.g. KADS - Breuker and Wielanga 1988) and training methods for knowledge engineers (Lafrance 1987, Wielanga and Breuker 1986).

Interviewing is a very broad methodology that encompasses a diversity of more specific techniques. A common distinction is between structured and unstructured interviews. Structured interviews follow some kind of method to elicit the knowledge. In an unstructured interview the main emphasis is to encourage the expert to speak without suggesting to her/him how the information should be presented. Presentation of different types of tasks can be used in either the structured or the unstructured interview situation.

(b) The unstructured interview

In the unstructured interview, questions are asked relatively spontaneously and when it is opportune to do so. An unstructured interview typically consists of questions from the interviewer, often long monologues from the expert, speech pauses and hesitations, and ungrammatical and unintelligible segments (Hoffman 1987). Unstructured interviews have been the starting point of many existing expert systems, and in fact many expert systems have been developed solely by using this technique.

Initially, unstructured interviews are useful to explore the problem domain and to identify types of users and problems encountered by the expert (Saveland and Stock 1989). However, it may be difficult for the knowledge engineer to know what questions to ask, which discussion trails to pursue and when to be sure that all areas of the expert's knowledge have been sufficiently covered. The resulting expert system may be biased, faulty or incomplete (Gordon and Gill 1989). Paradoxically, the unstructured interview is important to reduce initial bias, in the sense that the knowledge engineer may have preconceived ideas about the knowledge, its structure and possible representation (Stock 1990). The purpose of the unstructured interview is to listen to what the expert has to say, and allow the expert to present the knowledge in whatever form he or she wishes. In summary, the unstructured interview elicits declarative knowledge (Gordon 1989).

(c) Verbal protocol analysis

In think-aloud protocols, the expert is asked to think aloud while solving a particular problem or task. The problem or task can be existing and documented or hypothetical (Hart 1987). The think-aloud protocol is recorded and then analysed by protocol analysis. The two terms, protocol analysis and think-aloud protocol, are sometimes used interchangeably in the literature, but they are two distinct stages of the overall technique of verbal protocol analysis (Gordon 1989).

Protocol analysis involves refining, editing and re-organizing the transcript to reveal the expert's thinking process. Initially, this involves segmenting the verbal reports into analysable units by dividing them into separate phrases. These phrases are then grouped by connecting pronouns that indicate cross-referencing among phrases. Categories are subsequently developed to describe the grouped material relative to particular questions or objectives. Finally, sequences of occurrences of particular statement types are identified (Bainbridge 1985).

Ericsson and Simon (1980) provide a comprehensive discussion of how to collect and analyse think-aloud protocols. They discuss conditions that must be met for think-aloud protocols to provide valid data. Think-aloud protocols and protocol analysis must be used only for tasks in which verbalization is a natural part of thinking. Tasks that use idiosyncratic language (e.g., music) or where there is no natural verbalisation (e.g., perceptual-motor skills) are unsuitable (Olson and Rueter 1987). For example, two studies (Gagne and Smith 1962, Davis et al. 1971 - all cited by Ericsson and Simon 1980) involving the Tower of Hanoi problem (a perceptual-motor task) showed that verbalization of this task significantly affected immediate performance and learning.

Thinking aloud about a task may also interfere with the task, or the task (e.g., flying fighter planes) may not allow time for verbalization. Speaking while thinking aloud may also change the thought process. Intermediate steps are often omitted, because not every thought can be verbalized. This may result in difficulties in reconstructing the overall thought process. Finally, people tend to make misleading or inaccurate inferences about their own thought processes (Kassirer et al. 1982). In a comprehensive review of social psychological experiments, Nisbett and Wilson (1977) observed that people's judgments are generally significantly influenced by knowledge of outcomes. Hence, Ericsson and Simon (1980) recommended disregarding retrospective observations by subjects about their thought processes because these are subject to hindsight bias.

Actual reports about the use of thinking-aloud protocols and protocol analysis in the expert systems context are scarce. Nevertheless, Garg-Janardan and Salvendy (1987) claimed that most expert systems have been constructed with this method. Johnson et al. (1981) used protocol analysis to compare the procedure of diagnosis of congenital heart disease by expert system, versus diagnosis by individuals with different levels of expertise. Kuipers and Kassirer (1987) described the use of thinking-aloud experiments in a study of whether physicians use a causal model of the patient to support their problem-solving strategies. They also reported in some detail on how protocol analysis is applied to actual think-aloud protocols. Mitchell (1987) provided one of the few direct reports on the use of protocol analysis in the construction of an expert system (in the domain of media planning). While Mitchell (1987) claimed that verbal protocol analysis was most useful for the understanding of the media planning process, no examples of its actual use were given.

Overall, the use of this technique, while widely discussed and advocated in the knowledge acquisition literature (e.g., Hart 1987, Olson and Rueter 1987), is both time and expertise intensive. The technique can yield very detailed information about the expert's thought processes and knowledge representation (Kuipers and Kassirer 1987). The knowledge elicited is a combination of declarative knowledge and declarative inferences regarding strategies, i.e., knowledge about the proper sequence of steps used to perform a task or solve a problem (Gordon 1989).

(d) Structured interviews - questioning strategies

Introduction

In structured interviews, the interviewer follows some kind of focused strategy to elicit the knowledge from the expert. Structuring the interview minimizes the problems that are encountered in an unstructured situation (see previous section), speeds up the knowledge acquisition process and should lead to a more complete knowledge base. Structured interviewing techniques fall into three categories: questioning strategies, presentation of different tasks, and a combination of both.

Using questioning strategies during knowledge acquisition is important, as certain types of questions (e.g., those beginning with wh- as in who, whose, which, what and why) allow the person questioned leeway in providing an answer, while other types of questions may simply allow the person being questioned to agree or disagree (Woodbury 1984). Subtle changes in the wording of questions may also affect the listener's response (Loftus 1975).

Like the unstructured interview, the structured interview elicits declarative knowledge, but can also elicit procedural knowledge when focused on problem-solving activities.

Two examples of questioning strategies.

Lafrance (1987) listed six distinct kinds of questions directed at different aspects of the expert's knowledge. These questions can be related to five kinds of knowledge, resulting in what she terms a 'knowledge acquisition grid'. Lafrance claimed that, when used as a package, the questions produce an overall survey of the expert's knowledge, counter the knowledge engineer's bias for particular types of questions, and guard against unwarranted assumptions about the knowledge or its structure.

Question types are formulated to elicit an overview of the domain, to catalogue the knowledge categories, to ascertain their attributes, to determine interconnections, to seek advice and cross-check information. Knowledge is in five distinct categories: stories, metaphors, rules of thumb, maps and scripts for sequential and procedural knowledge. The resulting grid is based on the theory that there are multiple memories, each with particular features. The effectiveness of a question is then related to the amount of overlap with the memories in question. Furthermore, if the information is not accessible with one question, it may be retrieved through an alternative path.

The knowledge acquisition grid was developed as a training method for knowledge engineers, but it may be a useful method to guide knowledge engineers in the development of questioning strategies. However, no report on its actual performance in the development of a real expert system could be found.

Gordon and Gill (1989) developed a method to structure interviews based on a question probe method derived from research into prose comprehension. Besides providing a means to map the expert's knowledge structure, it also helps overcome the knowledge engineer's bias.

Question probes are based on an initial set of concepts, typically obtained in a short unstructured interview. These concepts form the basis of an initial knowledge network (also known as a semantic network or knowledge diagram), that depicts the basic concepts and relationships in the domain under investigation. This initial network also suggests types of relationships between the concepts, e.g., cause, reason, result, property, sub/supertype, example, implication, and consequence. Question probes are formulated around these initial relationships; others may become apparent later. For each node and relationship a set of questions (the question probe) is developed. Possible questions concern who, what is/are, why, how, what are examples of. In subsequent interviews, the expert is asked to verify the relationships expressed in the graph. The network is expanded through additional question probes until the expert and the knowledge engineer agree that the network is completed.

The completed network can be used to produce rules for rule-based systems, or it can be used for object-oriented programs and programs based on search of deep knowledge (i.e., knowledge that incorporates an understanding of causal connections). Gordon and Gill (1989) claimed that this method is easily adapted to any domain, provides a framework for interaction between knowledge engineer and expert, and keeps the knowledge engineer from exploring redundant avenues. The question probe method is similar to what Hoffman (1987) described as a structured interview and to an elicitation procedure for declarative knowledge briefly described by Mitchell (1987).

Presentation of different tasks and/ or problems to solve

Knowledge can also be elicited from the expert by presenting her/him with tasks involving the problem domain. Presenting different types of tasks or problems can be used either as the basis of verbal protocol analysis or for structured interviews. In the latter, discussion of the different tasks or problems forms the basis of the interview. The expert can be asked to solve these problems or tasks with or without verbalizing the internal thought processes.

The following types of tasks or problems can be presented to an expert (Hoffman 1987):

1 .Familiar tasks - tasks which the expert commonly engages in. These tasks can be real or simulated (i.e., historical data). Familiar tasks will probably elicit 90% of the expert's knowledge.
2. Limited-information tasks - a familiar task is performed, but some information is withheld.
3. Constrained-processing task - a familiar task is performed, but a constraint is imposed (e.g., a short time period).
4. Tough cases - analysis of a familiar case that was especially difficult.
5. Combinations of the above.

Limited-information tasks and constrained-processing tasks are suited to extracting information on selected subdomains, while analysis of familiar tasks gives insight into the overall problem-solving strategies used. By varying the task or the problem, the knowledge engineer can elicit declarative knowledge or domain-specific, compiled, procedural knowledge (Gordon 1989). Unfamiliar tasks or tough cases tend to elicit declarative knowledge, familiar tasks procedural knowledge.

3.2.3 Psychometric methods

(a) Introduction

In the methods discussed above, the expert is asked directly about her/his knowledge. Olson and Rueter (1987) suggested that these 'direct' methods rely on the ability of the expert to think about and articulate this information. But this information may not always be available; in fact, an increase in expertise may be accompanied by a decrease in the ability to verbalize this expertise (Anderson 1983). Furthermore, many knowledge acquisition methods are subject to bias and communication problems between the expert and the knowledge engineer. Psychometric methods such as multi-dimensional scaling, network scaling, cluster analysis, the repertory grid technique and task analysis may offer an alternative. These more formal techniques (in the sense that they are more quantitative than qualitative) are also better suited for adapting to automatic knowledge acquisition (see especially Gaines and Shaw's work on repertory grid analysis, 1981).

(b) Repertory grid analysis

The repertory grid technique has been used successfully in many domains (e.g. business management, psychology, anthropology). Gaines and Shaw (1981) first proposed that Kelly's personal construct psychology (Kelly 1955) could be used as a knowledge acquisition tool. Kelly's personal construct psychology is a theory of human cognition based on the way that individuals seek to predict and classify events (Shaw and Gaines 1987). One of the psychotherapeutic techniques developed by Kelly is a Repertory Grid Test for eliciting role models. In this test, the client compares, lists, and rates role models. The resulting scores are used to derive and analyse the client's character traits (Boose 1984).

The first step in construction of grids in knowledge acquisition is to list elements or problem solutions. For a wine advisor, for instance, the knowledge elements might be different types of wines or different types of food. The expert is then asked to describe traits that discriminate amongst the elements or solutions using rating scales, triads or both. When the triad method is used, elements or problem solutions are presented in groups of three and the expert is asked in which way two of these elements are alike and differ from the third element. A scale rating allows more distinction between the elements and more than three elements to be rated at once. The expert is asked to rate the elements between two extremes of difference.

Knowledge elements and their values are mapped to produce a two-dimensional grid of relationships (Shaw and Gaines 1987). A qualitative index of this relationship is provided by asking the expert to rate elements or problem solutions in terms of traits (Gordon 1989).

With the repertory grid method, characteristics of the components of the problem space, ranges of values of these characteristics and unique approaches and heuristics of the expert's problem-solving strategies can be obtained. Because the elicitation of knowledge is so structured, significant time reduction in the analysis of the elicited data can be obtained (Garg-Janardant and Salvendy 1987). The technique can be used to elicit declarative knowledge, but Gordon (1989) warned that it is unlikely that declarative knowledge about why something is the case or how something should be accomplished is could be elicited with this method.

Furthermore, an expert system developed with the repertory grid technique may not replicate the way an expert uses heuristics to solve a problem, as the repertory grid operates in a backward-chaining fashion (i.e., pairs or triplets of possible solutions are presented and then distinctions are made between them - Schachter and Heckerman 1987).

The repertory grid technique, in combination with other psychological scaling techniques, (i.e., network scaling, multi-dimensional scaling) has been successfully implemented in a number of knowledge acquisition tools (e.g. PLANET - Shaw 1981, ETS - Boose 1984, AQUINAS - Boose 1984). Gaines and Shaw (1987) claimed that use of a computer to interview experts overcomes many of the problems encountered in human-human interactions. These problems include eliciting incomplete, imprecise and inconsistent knowledge, and interpersonal problems inherent in the knowledge engineer-expert relationship. Some experts may feel threatened by the prospect of an expert system encroaching on her/his job and may have difficulties in communicating with the knowledge engineer. An equal number of experts will welcome the assistance of a computer as well as viewing communication with others as part of their job. In addition, a domain may be sufficiently indistinct to make a clear identification of its elements difficult. Also, many of the smaller and more straightforward expert systems would not warrant the use of an expensive knowledge acquisition tool.

The repertory grid can be used successfully as a person-person knowledge acquisition technique. Benfer and Furbee (1989) reported its use as a manual knowledge acquisition tool in the development of an expert system for soil classification in the Peruvian Andes. They also drew analogies between knowledge acquisition by cultural and linguistic anthropologists and knowledge acquisition for expert systems development. Benfer and Furbee are engaged in exploring what they term "out-of-awareness knowledge".

3.2.4 Comparison of available methods

Most statements about the utility of different knowledge acquisition methods come from two sources: retrospective descriptions of how knowledge acquisition has been carried out in a particular project (e.g., Prerau 1987), and theoretical papers on different techniques (e.g., Hoffman 1987). The weakness of the case study approach is that results may not be applicable to other expert systems projects (Shadbolt and Burton 1989). Examination of theoretical papers allows the knowledge engineer to categorize knowledge acquisition methods in a number of ways.

Gordon (1989) suggested that knowledge acquisition methods can be categorized by the type of knowledge elicited. Techniques requiring introspection (interviews, psychometric methods) elicit declarative knowledge, whereas asking the expert to perform a task without verbalizing his/her thought processes yields procedural knowledge. Procedural rules can be inferred by evaluating the relationship between situational characteristics and expert performance. Gordon (1989) contended that methods that ask the expert to perform a task and also explain his/her behaviour (i.e., verbal protocol analysis) elicit declarative as well as procedural knowledge. The information elicited by think-aloud instructions is declarative, while information indirectly provided by input/output characteristics is procedural in nature.

The literature about procedural versus declarative knowledge and the kinds of knowledge particular methods can elicit is confusing. For instance, Olson and Reuter (1987) distinguished between direct (interviews, verbal protocol analysis, task performance) and indirect methods (psychometric techniques). They claimed that direct methods could elicit all types of knowledge, while indirect methods elicit only knowledge about relationships. However, this distinction is not very useful for deciding which technique to use and the type of knowledge it will yield.

The difference between declarative and procedural knowledge is important, because growth in expertise is marked by an increase in procedural knowledge. Anderson (1983) suggested that experts encode new knowledge as declarative knowledge, i.e., the set of facts relevant to a particular task. To access this knowledge, domain-general procedures (i.e., procedures that can be applied irrespective of the content) are used. Over time, errors in the initial understanding are detected and eliminated. The declarative knowledge is transformed into domain-specific procedures by strengthening the connections among the various elements required for successful performance; these domain-specific procedures become increasingly automated.

Lafrance (1989) suggested that the different knowledge structures of experts should be taken into account by the knowledge engineer during knowledge acquisition. Knowledge engineers need to move beyond unstructured interviews as a primary method of knowledge acquisition (as suggested by Weiss and Kulikowski 1984) and use a more structured knowledge acquisition process such as knowledge acquisition grids (Lafrance 1989). Experts are better at applying and using their knowledge, and it is therefore important to observe the expert in what Schon (as cited by Lafrance 1989) termed 'knowing-in-action'. To elicit knowledge of this type, the expert must be probed while engaged in problem-solving; verbal protocol analysis is a useful technique for this purpose. Additionally, experts focus on goals rather than effects. For instance, experts, when presented with a case description, are likely to see it in terms of what is being put into effect rather than focusing on what has just taken place. The implication for knowledge engineers is that they must understand the expert's objectives to fully understand the decision-making process. This can be achieved by observing the expert in everyday situations, rather than in idealized problem-solving activities.

The choice which particular technique or combination of techniques to use also depends on the type of expert system to be developed, the expert(s) available, and financial resources. Kidd and Sharpe (1989) rightly pointed out that currently no formal or even informal characterization of different knowledge domains exists. Consequently it is not possible to classify knowledge acquisition techniques in relation to different domains or tasks. A characterization of different types of experts would also be helpful when selecting a particular knowledge acquisition technique, but again it does not exist.

In summary, both declarative and procedural knowledge are important. Using unstructured interviews alone is not sufficient. A combination of techniques (e.g., unstructured interviews, structured interviews and verbal protocol analysis) is the best choice. The knowledge engineer must be responsive to the circumstances of each particular project.

3.3. Knowledge acquisition leading to the first prototype for insect sampling plans

3.3.1 Introduction

Kidd (1987) described knowledge acquisition as a linear three-step procedure. The three steps are: eliciting knowledge from the expert, interpreting it to infer the expert's underlying reasoning process and knowledge and using this interpretation to guide the construction of a model of this process. In reality, a feedback loop exists between the first and the last step of this process. This feedback process is often facilitated by the development of intermediate rapid prototype expert systems. Such prototypes serve as a discussion and verification point between expert and knowledge engineer.

A number of knowledge acquisition methods were used in this study at the different stages of the knowledge acquisition process for the first prototype. These were initially unstructured interviews and literature research, followed by structured interviews, task analysis, and verbal protocol analysis. Psychometric methods such as repertory grid or scaling methods were not used.

The process of knowledge acquisition for the first prototype consisted of the following stages: describing the domain in broad terms, obtaining problem characteristics and a task decomposition, and implementing and evaluating the first prototype. This is similar to the steps outlined by Breuker and Wielanga (1987).

3.3.2 Description of the domain

(a) Methods used to derive a description of the domain

After securing the cooperation of the major expert (C. Dyson - MAF Technology, Lincoln, New Zealand) a number of textbooks and papers on insect sampling plan design were reviewed. These reviews resulted in an initial description of the domain, provided an understanding of the critical variables that affect the insect sampling plan design, and formed the basis of a sequence of initial interviews with the main expert and a number of auxiliary experts.

(b) Description of the insect sampling plan design domain

A general description

An insect sampling plan is an important part of most entomological research, whether the focus is a basic biological or ecological study or an evaluation of the success of a pest management effort. Sampling plans are used to acquire data which can be analysed by known statistical methods.

Rarely can all insects in a given environment be counted. Instead, estimation of the population size is achieved by sampling the target population. Numerous techniques are available for this purpose, but as Morris (1960) indicated, the principles of population sampling are universal. Techniques necessarily differ according to diversity of lifecycles and habitat of the insect and objectives of research.

Morris (1960) names the following components as common to all insect sampling plans:

1.The spatial distribution pattern of the insect.
2.Sample size estimation or magnitude of change to be recorded.
3.Selection of the sample universe.
4.Definition of the sampling unit.
5.Distribution of the sample unit in time and space.
6.Selection of the unit of measurement (unless direct counting is involved).
7.Major sources of variance.
8.Cost efficiency of the sampling method.
9.Biology of the insect and knowledge about their habitat.

To determine some of these components, especially spatial distribution and optimal sample size, a preliminary sampling plan is necessary. In a preliminary sample, different sampling methods, sampling units, and sizes are compared for their cost efficiency, statistical suitability and precision. Size, nature and arrangement of sample units can all have effects on the data sampled.

The preliminary sample also reveals the spatial distribution pattern of the subject insect. The spatial distribution is a major consideration of any sampling procedure (Southwood 1976) as it influences sample size, sample unit and spatial placement of the sample unit.

The habitat in which the insect to be sampled occurs is usually called the sampling universe. Its extent must be clearly defined. The sampling unit (i.e., some fraction of the sampling universe) should be representative of the insect and its environment, be stable, lend itself to a conversion to unit area, and be easily delineated in the field (Morris 1955).

The level of precision required is closely linked to the magnitude of population change one wants to record. Southwood (1976) suggested a precision of 25% to detect population changes for damage assessment and control studies. For life-table studies, a higher level of accuracy (10%) is advised.

Most statistical techniques require data to be collected in a random fashion so that unbiased estimates of the population parameters can be calculated. However, in entomological research the use of stratified random sampling procedures is common, since an insect's distribution in space is often clumped. Biological knowledge can be used to eliminate strata in which few insects would be found, thus improving the level of precision for the calculation of the mean (Southwood 1976). Stratified random sampling is often more cost-efficient, and biologically more meaningful (Morris 1960), and minimizes the variance (Southwood 1976).

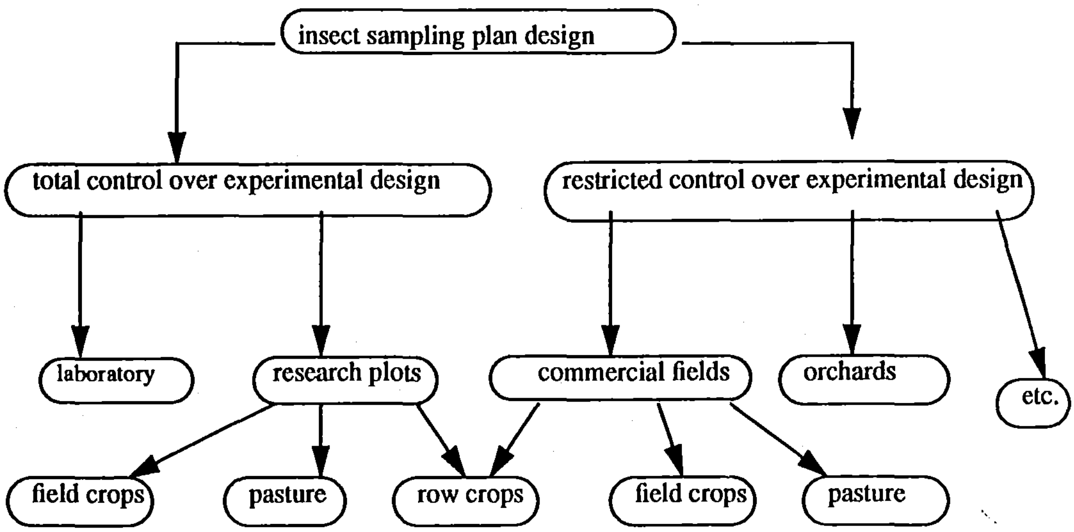
A subdivision of the domain

Entomological as well as statistical knowledge contributes to insect sampling plan design. The insect sampling plan design domain can be divided into situations where the experimenter has either total or restricted control over the experimental design (Figure 3.1). Total control means that the experimenter has freedom over how to arrange the environment (forming the habitat and the sampling universe of the insect). Restricted control implies that the environment is already arranged in some form, i.e., spatially restricted control. Certain environments are associated with either of these conditions (e.g., an orchard usually results in restricted control over sampling plan design, because it is commonly already planted and certain spatial restrictions therefore exist).

When developing a prototype expert system it is common to chose a 'vertical slice' of the domain, rather than designing a system that represents a skeleton of the whole field. The finished prototype represents what other branches might look like if the system was expanded. The branch chosen must also have some importance by itself for users.

The apple orchard domain was chosen for initial consideration. An orchard environment represents a fairly predictable environment in terms of physical structure (e.g., trees, shelter, spacing of trees). This structure eliminates complications introduced by a more variable environment such as pasture or natural forest. The orchard environment constitutes an example of restricted control over experimental design. Additionally, orchard environments (especially apple, but also kiwi fruit, vineyards etc.) play an important role in the New Zealand economy, and the effects of insects on these orchards is of great interest to entomologists.

Figure 3.1: Control exercised in different types of experiments in entomological research.



3.3.3 Problem characteristics and task decomposition

(a) Methods used

General

The aim of this phase was to delineate the problem as an input/output model and to divide the task into subtasks. An input/output model was used because it conceptualizes the broad information flow and identifies the data items needed to solve the problem. Task decomposition provides an idea of the steps involved in performing a particular task (Belkin 1987) and the overall strategy used by the expert to solve the problem.

Interviewing techniques were chosen because these techniques seemed relatively easy to learn and execute. The pitfalls of these techniques have been extensively researched. Interviews elicit declarative knowledge, but they can also be combined with problem solving. Procedural knowledge in the form of rules can than be accessed.

Unstructured interviews

The first two interviews with the major expert were conducted as unstructured interviews. Unstructured interviews were used to explore the problem domain, elicit general strategies and concepts, and get a 'feel' for insect sampling plan design. The emphasis in the unstructured interview is on listening and allowing the expert to present the information in whatever form he or she wishes (Gordon 1989). General questions are asked to initiate in depth discussion of particular topics. Typical general questions the author asked in these interviews were:

1.'Can you outline the general steps for a preliminary design and why they are necessary.'
2.'What are the essential information items you need for a design ?'
3.'What kind of information would you find in reference books ?'
4.'How do you define ... (e.g., random, strata)?'
5.'What is a ... (e.g., sampling frame)?'

Interviews with auxiliary experts

Knowledge contributing to the domain of insect sampling plan design is not exclusively of a statistical nature, but also encompasses entomological knowledge. For this reason three unstructured interviews were conducted with experts in the field of entomology. Two of these interviews concentrated on the entomologist's view of insect sampling plan design, while in the third interview the topic was types of sampling objectives.

Structured interviews

Part of expert knowledge is an understanding of how to recognize relevant elements and how these elements interact (Lafrance 1989). However, much of this knowledge is unconscious and the expert may find it hard to verbalize this knowledge in an unstructured situation. This problem can be overcome by structuring knowledge acquisition and by observing the expert while he or she is involved in problem-solving.

Insect sampling plan design is a domain that involves clients and advisors. To model one part of this interaction, it seemed prudent to make knowledge acquisition as similar to real life as possible.

Interviews three to eight used a constructed test case (using Teulon, 1983) to focus the interview. This test case specified a particular insect, study area layouts, research objectives, proposed sampling unit and resource constraints. The intent was to simulate a consultation between a biometrician and an entomologist. The test case was used to elicit general and specific rules about sampling design. This was achieved by first dicussing the presented test case in detail. In later interviews the author extrapolated from these by asking questions like: 'What would happen if....'

The structure of each interview was as follows. First, the author would remind the expert of the topic of the previous meeting and ask if the expert had anything to add. Second, the author would then ask the expert to clarify any questions that had arisen from the analysis of the previous interview. Finally the author would outline the topic of the present interview and the interview proper would begin.

Analysis of interviews

The overall analysis of each interview proceeded in stages. All interviews were audio-taped and transcribed verbatim immediately after the interview. They were analysed using protocol analysis. Transcripts were split into phrases, and important concepts identified in each phrase. Relations between the identified concepts are established and graphically represented (Bainbridge 1985). The transcripts were also inspected for any obvious rules, or rules were inferred where possible. Each interview lasted between 60 and 90 minutes.

Figure 3.2 shows an example of how protocol analysis was used on an excerpt from the second interview. Transcripts were split into phrases, major concepts were identified and relations between them were established. The interview is summarized around these concepts and a list of information volunteered by the author and information requested by the expert is made. The transcript is scanned for possible rules; these may have been stated directly by the expert or sometimes rules can be inferred from the context. Questions that need to be asked in future interviews are listed, along with the major areas covered in the interview. Notes are also made about each interview in term of general impression, objectives of interview and improvements for further interviews. Finally the objectives for the next interview are recorded (see Appendix 2 for an example interview and the analysis performed on it). After two or three interviews all the material is reassessed and the expert questioned about any discrepancies and unanswered questions.

(b) Results

Results of analysis of interviews with the major expert

Interviews one and two showed that it was hard for the statistician to talk about advice without a specific example, e.g., a case history or a problem to solve. Without the help of a case history to focus the interview most rules elicited were of a general type.. General rules were of the form:

> "If more than two cultivars exist, use cultivar as the basis for stratification."
> "Avoid sampling next to oddballs."
> "Sampling lots of zeros reduces the overall sampling efficiency."

It was impossible to use rules of this kind for the first prototype. Only when the expert was presented with a very specific case and some hypothetical variations to it was it possible to elicit more specific rules. These rules were of the following type:

"If tree system = intensive
and sampling unit = leaves
then divide into two height strata."

The task of designing an insect sampling plan for the orchard environment can be subdivided into a plan for the preliminary design and a plan for the main design. For both subtasks, decisions must be made pertaining to the selection of the trees themselves (between-tree decisions) and decisions on how to subdivide the selected trees (within- tree decisions). These decisions include how to stratify the sampling area and how to select trees within a stratum, or correspondingly, how to stratify within a tree and how to select within-tree sampling units (Figure 3.3).

Figure 3.3: Insect sampling plan design decisions for the orchard environment.

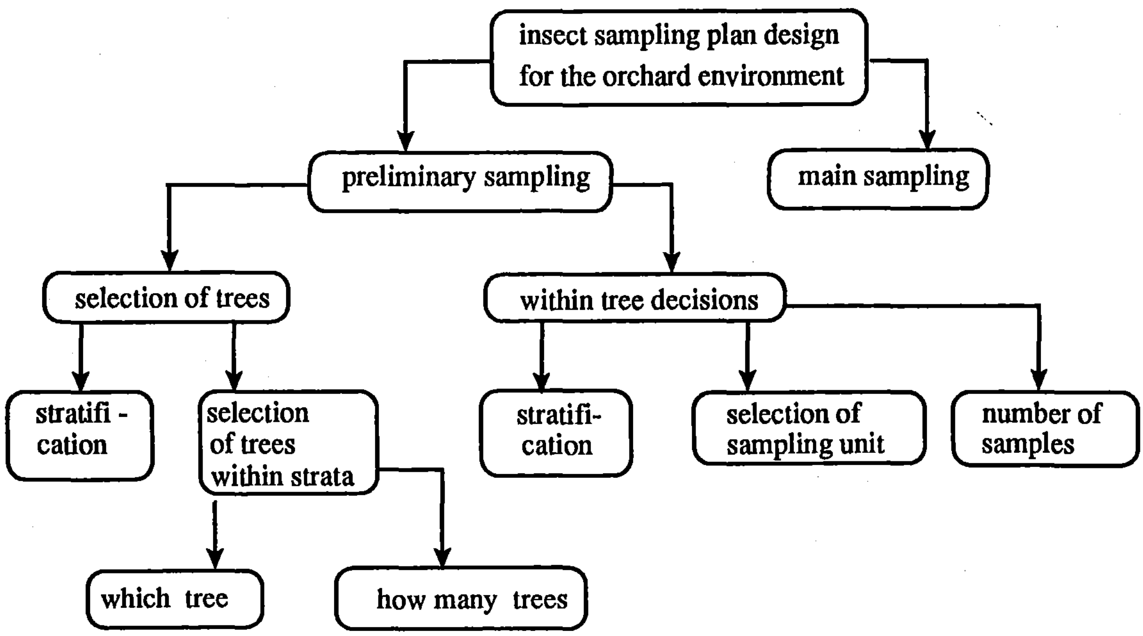


Figure 3.2: In this protocol excerpt the expert talks about common distributional characteristics. Note how the transcript is split into phrases, the major concepts are underlined and connected by arrows to related concepts.

1 The main point is whether there is something unusual about the situation.

2 or is it normal

3 what category does it fit in

4 that we are familiar with

5 does it fit into existing categories

6 normal, negative binomial, Poisson

7 obviously you have some idea before you start

8 where you expect to be

It was impossible to use rules of this kind for the first prototype. Only when the expert was presented with a very specific case history and some hypothetical variations to it was it possible to elicit more detailed rules. These rules were of the following type:

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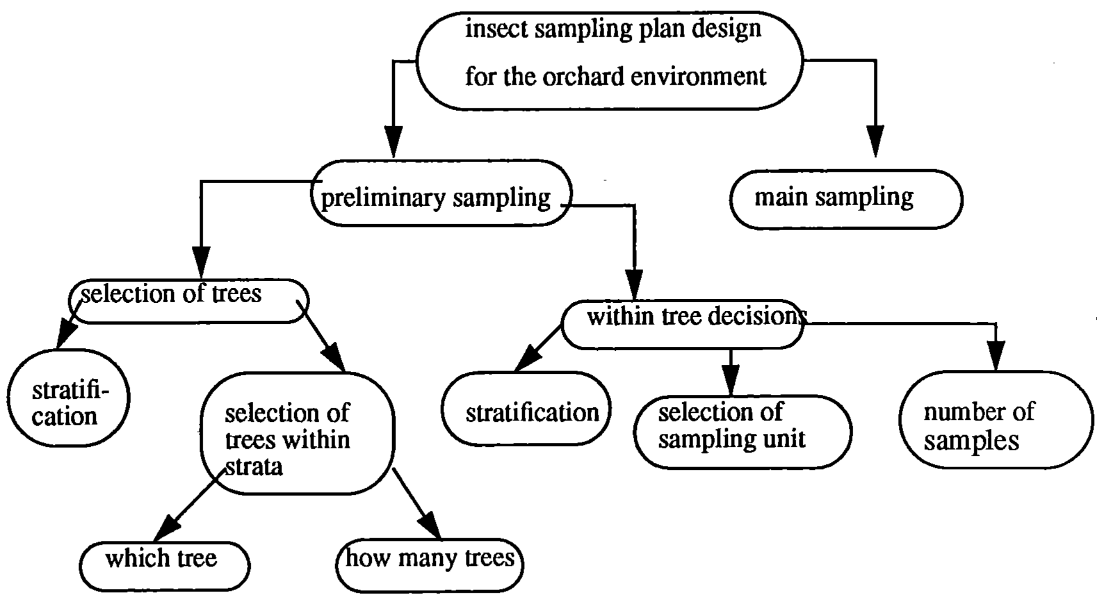
Figure 3.3: Insect sampling plan design decisions for the orchard environment.

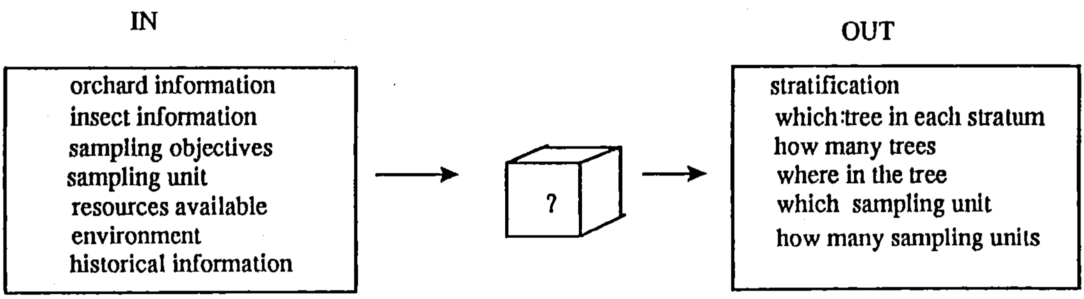


The input/output model depicts the information necessary to make these decisions. Information on the orchard layout, the insect in question, sampling objectives, possible sampling units, resources available, the overall environment of the orchard and historical information on previous sampling plans are all necessary to make the decisions involved in sampling plan design (Figure 3.4).

Results of analysis of interviews with the other experts

The thinking of the entomological experts was in accordance with the task decomposition elicited from the main expert. All experts interviewed stressed the importance of a clearly defined sampling objective and its eventual refinement as the project evolves. The expert specifically interviewed about sampling objectives described it as a continuum between intensive studies on one insect (needing absolute population estimates) and insect surveys (relative population estimates through time and space). The problem is to balance generalized objectives versus sampling for a specific organism with peculiar phenology governed by local conditions. This view agrees with the entomological literature on insect sampling objectives (Southwood 1976, Morris 1960).

Figure 3.4: An input/output model for insect sampling plan design in the orchard environment.



3.3.4 The first prototype and its evaluation

(a) Introduction

A common procedure in expert systems development is rapid prototyping (Stock 1987). This involves producing a small system early in the project to show the expert. The rapid prototype is used as a discussion point for further interviews and developments. This was the approach taken here. Concepts and their structural relationships were not only identified, but also evaluated by implementing the information elicited from the interviews with the main and auxiliary experts in a prototype expert system.

(b) Description of the first prototype and lessons learned

The first prototype consisted of 25 rules and was implemented in CLIPS, an expert systems shell developed by NASA. This shell uses a syntax similar to OPS5 (Culbert and Riley 1986). The prototype advised users on the design of preliminary and main sampling plans assuming the orchard was of a particular physical layout. The system considered such variables as shelter, size of trees, habitat and aspect and was text-based (see Appendix 1 for the decision tree developed preliminary sampling plan design).

The prototype was evaluated with the expert in an interview situation. The evaluation led to the following conclusions:

1. A graphics-oriented user interface would enhance the system considerably by facilitating communication about orchard layout and the final sampling advice given (section 5.2.3).

2. Experts from related disciplines, especially horticulture, needed to be interviewed to gain additional information (i.e., orchard layout, user perception).

3. Research reported in the entomological literature rarely goes into sufficient detail to be presented as case histories or to form the basis of test cases in a knowledge elicitation session between expert and knowledge engineer. This detail can be found in post-graduate theses, but only a limited number of these have been produced in New Zealand. Hence suitable case histories are severely lacking

4. Despite trying to elicit general rules from the expert, the rules elicited so far were still very specific. i.e., in the preliminary they resulted in only two different sampling schemes. It was also not clear which of the rule conditions were essential and which were non-essential in coming to a particular design decision..

3.3.5 Summary

Structured and unstructured interviews were conducted to acquire knowledge for the first prototype. Unstructured interviews were use to elicit general concepts and strategies and to give the expert the opportunity to present his knowledge. The structured interviews involved problem-solving of a particular test case with and without introspection. In this way, declarative as well as procedural knowledge could be elicited. The reasons for this choice of techniques were ease of use, clear indication of possible pitfalls. The interviews were analysed by protocol analysis.

The availability of test cases is sometimes given as a criterion for selection of an expert systems application area. Test cases are considered a foundation for refining the prototype (Harmon and King 1985) and for validating the system (O'Keefe et al. 1987). The observed lack of case histories, which form the basis of test cases, presented a serious problem for continuing development of an expert system in this domain.

3.4 Knowledge acquisition leading to the second prototype

3.4.1 Introduction

On completion of the first prototype it became clear that a major problem in the continued refinement of the first prototype was the lack of suitable test cases. Test cases can be case histories, or case histories can be used to create hypothetical or synthetic test cases. Test cases present the expert with a problem to solve or a task to perform.

The types of decisions involved in designing a sampling plan had been determined (i.e., within-tree and between-tree decisions), but the rules developed to that point were still too specific to deal with a wide range of sampling design problems.

It was necessary to develop a method that would incorporate the useful knowledge (i.e., types of decisions involved) elicited so far, and that would allow continued and efficient knowledge acquisition.

The use of knowledge elicitation through anything other than test cases was not investigated. Use of the repertory grid technique, for instance, seemed inappropriate because it tends to yield only declarative knowledge. Expert knowledge combines procedural and declarative knowledge, procedural knowledge can be elicited by observing the expert 'in action'. Many techniques (i.e., verbal protocol analysis) assume the existence of test cases.

3.4.2 Theoretical and methodological considerations

The development of a knowledge acquisition technique to overcome the observed lack of readily available case histories, or other information that could be turned into test cases, in the insect sampling plan design domain was influenced by a number of theoretical and methodological considerations.

Simon (1969) and Tversky (1972) argued that in choosing amongst alternatives, people use procedures that simplify their decision-making. These decision-making procedures can be represented with hierarchical models of trees, with decision criteria at the node of the trees (Gladwin 1976).

Besides Lancaster (1966) and Tversky (1972), Gladwin (1976) assumed that each alternative choice has a set of characteristics. For example, among the characteristics of a particular sampling plan (in a hypothetical choice between alternative plans to follow) are sampling method, resources available, and so on. This theory assumes that all characteristics are discrete or are treated as a constraint (e.g., tree number explain how people in everyday life make choices about objects, but has also been expanded to domains that require expert knowledge (for an example, see Gladwin 1976).

A number of different models for describing how people make decisions have been put forward. These models can be divided into strategies that confront the conflicts inherent in the choice situation and strategies that avoid the conflict. The latter are non-compensatory models i.e., they allow the decision maker to trade-off low values of one characteristic against high values on another, while non-compensatory models do not permit this.

Hogarth (1987) described in some detail different types of compensatory and non-compensatory models. Compensatory strategies have the advantage of taking all relevant information into account, but they are difficult to execute from a cognitive point of view. The opposite is true for non-compensatory strategies, which are more easily executed, but as they interact with the way the decision maker acquires information, they may lead to choices that do not reflect the true preferences of the decision maker. Examples of compensatory models are: the linear, additive difference and the ideal point model. Examples of the non-compensatory model are the conjunctive, disjunctive, lexicographic and elimination by aspect model.

Choice strategies differ on the information processing load the impose on people and wether the information is evaluated inter or intra dimensional. The actual choice of strategy used by a person depends on the number of choices involved. Commonly a combination of strategies is used. Initially non-compensatory methods may be used to decrease the information-processing demands to a manageable size and latter compensatoy methods are used to make a more detailed analysis of the remaining information.

The technique of experimentation is the basis of scientific research and is an integral part of any description of the scientific method. An experiment requires a parallel set of tests that are identical in all respects except one. This standardization permits evaluation of individual variables or constants versus test results. The experimental method can also be viewed as a way to explore the effect that the choice among different characteristics has on the outcome of the decision, and presents a guideline for the systematic presentation of test cases to the expert. Additionally, procedural knowledge can be indirectly inferred from input/ouput characteristics.

3.4.3 Characteristics of insect sampling plan design

(a) Introduction

The following describes the characteristics that define the choice among alternative insect sampling plan designs. The characteristics described below were culled from the literature and interviews with the expert as part of the development of the first prototype. To cut down on the possible number of test cases, only those characteristics that seemed to have a great influence on the choice between alternative plans were used.

Insect behaviour is often very complex, given the many different characteristics that may manifest (e.g., the insect might be nocturnal or might emerge on certain dates). Its influence was not investigated in detail, because sampling plans can be constructed that in most cases will yield the desired information without taking this aspect into account. These plans will often involve greater sampling numbers than those where insect behaviour is taken into account. However, insect behaviour can sometimes be inferred from data collected in the preliminary sample and sampling numbers in the main sample can then be reduced.

An insect sampling plan for the orchard environment can be either preliminary or the main sampling plan. Data collected from preliminary sampling is a prerequisite for the main sampling plan.

Orchard layout and microhabitat of the insect were the characteristics investigated for the choice of the preliminary sampling plan. The objective of sampling is a further deciding characteristic, but to simplify the problem, the sampling objective was held constant. In all cases the objective was: investigation of the relative population levels of a certain insect life stage.

Relative population levels are estimated by measuring the population in unknown units using various forms of trapping or catch per unit efforts. Absolute population levels refer to the number of animals per unit area by sampling a unit of habitat or by using marking techniques (Southwood 1976).

The main sampling plan design was investigated using the same characteristics. Additionally, effects of distributional characteristics, cultivars, strata and shelter preference of the insect were investigated.

(b) Description of characteristics

Orchard layout

Orchard layout varies from country to country in response to environmental conditions and management practices prevailing. Three interviews with leading experts on orchards (Dr. D. Jackson, Lincoln College, Dr. J. Brunner, Washington State University, Dr. T. Webster, MAFF - Great Britain, 1988) were conducted to survey typical orchard layouts for New Zealand, USA and Great Britain respectively. The purpose of the interviews was to investigate whether there were marked differences in the typical apple orchard layout and what these differences were. The interviews were audio-taped, transcribed and analysed in the same manner as described previously (Section 3.3).

New Zealand orchards are characterized by a small area (up to 10 ha). These are typically subdivided into blocks of 1 to 2.5 ha. Each block contains several cultivars and, because wind is a major environmental factor, a block is surrounded by shelter. The training system most commonly used is the central leader system with a semi-intensive rootstock. By comparison, United States orchards may reach up to 1000 ha planted in just one cultivar with no shelter. In Great Britain orchards are even smaller than New Zealand orchards and cultivars are alternated every other row. Planting density (a function of rootstock and training system) varies but is often very high.

When sampling in an orchard, the researcher may take samples from the whole orchard or part of it. Sampling area layout is chiefly characterized by spatial and numerical information: how many trees per row, how many rows, how many physically separated sampling areas. Under New Zealand conditions, information on the number of different cultivars and their spatial repetition is useful for stratifying the sampling area and may give information on insect preferences. Orchard subblocks will generally not exceed 2.5 ha.

Ten plans of actual orchards or parts of orchards used as sampling blocks in other entomological studies were available (see Figure 3.5 for a sample orchard, Appendix 3 for the full set) to provide a range of the three chief spatial characteristics of sampling area layout. They were also used to examine the effect of number of cultivars per sampling area. An examination of the 10 orchard layouts showed that cultivars are never repeated more than three times per study block.

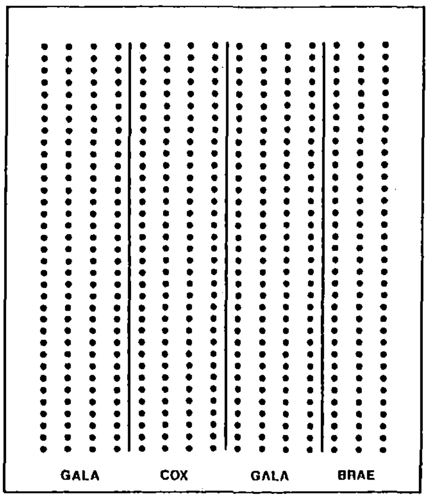
Microhabitat of the insect

Pielou (1977) divided organisms into those that are confined to discrete habitable sites or units (here termed microhabitats) and others that occupy a continuum of space (e.g. air or soil). The latter have no natural sampling units. Insects are often confined to discrete habitats.

In the orchard environment, the possible microhabitats are leaves, blossoms, fruit and bark. Non-discrete insect habitats in the orchard include the air and the soil. Air is also the only habitat that contains adult insects only. All other lifestages of insects may be found in the microhabitats (leaves, blossoms, fruit and bark) or in the soil.

The effect of each microhabitat, as well as the effect of insects sampled in the air, on the choice of sampling plan was investigated.

Figure 3.5: Sample orchard layout.



Distributional characteristics of insects

Different insects and insect stages may be arranged in space in a uniform, random or clumped pattern. A particular pattern can be described in terms of a normal, Poisson or negative binomial distribution. Pielou (1977) indicated, however, that there is no direct correspondence between arrangement of insects in space and statistical frequency distributions. In statistical terms, distribution refers to the way in which values occur with different frequencies in a number of possible classes. The distribution that most accurately describes a data set influences the number of samples needed in the main sample and the placement of the samples. The influence of all three distributions on the main sampling plan was examined.

Insect preferences

Insects sometimes show preferences for certain cultivars (Ito et al. 1977), parts of the tree (Tomkins 1983) or parts of the orchard (Le Roux 1961). One purpose of the preliminary sample is to alert the researcher to these possibilities. When creating data sets, these alternative preferences were incorporated.

3.4.4 Knowledge acquisition by simulating test cases - a technique to generate test cases in the insect sampling plan design domain

(a) Introduction

The purpose of knowledge acquisition by simulating test cases is to discover the set of characteristics used to select a specific sampling plan. The number of potential characteristics and hence combinations is potentially large. The interviews leading to the first prototype indicated, however, that only a few characteristics have a great overall influence on the resulting sampling plan. Those particular characteristics were investigated.

The actual method for discovering the set of characteristics that constrain the choice of sampling plan is an adaptation of the experimental method. Two characteristic at a time are varied, resulting in a specified number of hypothetical test cases. This set of test cases tests the effect two particular characteristics have on the choice of sampling plan. The results are recorded in a two-dimensional matrix with each dimension representing the variations within a characteristic (see Table 3.1 for a sample matrix). In this the method is not dissimilar to psychometric techniques used for knowledge acquisition. The matrix representation makes it easy to formulate rules from the entries. The redundant (those that do not influence the choice of sampling plan) and the constraining characteristics can be easily identified.

The test cases were presented to the expert in an interview/ problem-solving situation. The expert was asked to provide an insect sampling plan for a particular set of characteristics.

Table 3.1: Sample matrix showing possible variations of insect microhabitat and orchard layout.

	Fruit	Leaves	Blossoms	Bark	Air
Orchard Layout 1					
Orchard Layout 2					
Orchard Layout 3					
Orchard Layout 4					

(b) A standardized form for presenting the test cases

In order to ensure standardization of the information presented for each test case, a standardized form to present this information was developed. This form was later also used as a checklist that provides the entomologist with an idea of the sorts of information the statistician/expert system requires to advise on the preliminary design (see Chapter 5.2.4).

Methods

Three structured interviews with the expert were conducted. The interviews were audio-taped, transcribed, and analysed as described in previous sections (see Section 3.3.3). In the first interview the expert was asked:

> "Imagine the perfect client has come to seek advice from you. What kind of things would she know?"

The expert was also presented with a list of items assembled from previous interviews and the statistical literature and asked to comment on these. After the first interview a checklist was assembled. The two remaining interviews were used to refine this first checklist. The checklist has three major parts: the orchard environment, the insect and the sampling methodology (Figure 3.6).

Figure 3.6: The initial checklist for insect sampling plan design in the orchard environment.

Before the first visit to the statistician a number of observations should be made in the orchard, and certain information relating to the insect and the sampling methodology gathered. This checklist was designed to aid this process.

1. The Orchard Environment

Please draw a plan of the study blocks(s) noting:

- The number of different cultivars,
- the growing system used (including height, shape & spacing of trees),
- shelter information,
- surrounding land to use/crops,
- important environmental factors,
- important management practices, and
- any treatment applied.

2. Insect Information

- What is the lifecycle of the insect? Note any complications that could affect the timing of the sampling window.
- Which lifestage(s) do you wish to sample?
- Size of lifestage(s) to be sampled?
- Environmental preferences (if known), of lifestage(s) to be sampled?
- Are there any other species intimately involved with lifestage(s) to be sampled?
- Does level of mortality vary greatly from lifestage to lifestage?
- Anything else affecting insect numbers?

3.Sampling Methodology

- Sampling objective?
- Is the data capture secure and reliable?
- Will counting occur in situ or in the laboratory?
- What are the possible sampling units?
- Are the possible sampling units constant in size?
- What is the time it takes to sample each possible sampling unit (including the time spent to go from one unit to the next)?
- What is known from the literature about statistical properties of the insect?

(c) Methods and results for the preliminary sampling design

Methods

Test cases to investigate the preliminary sampling plan design were presented to the statistician using the standardized form. Interviews with the statistician were audio-taped, transcribed and analysed as described in previous sections (3.3.3). The effect of orchard layout and insect microhabitat was investigated (Table 3.1).

Results

Preliminary sampling plan design can be divided into decisions pertaining to tree selection and within-tree decisions (Figure 3.3). Study block layout influenced tree selection the most. Table 3.2 shows the study block layout for each hypothetical test case presented and the advice given by the expert (i.e., trees to sample per cultivar subblock). The number of trees to sample per cultivar subblock ranged from one to three, depending on the number of cultivar subblocks, trees per row, rows per cultivar subblock and total tree number per cultivar subblock. Figure 3.7 shows the decision tree developed from this table.

Within-tree selection consists of selection of sampling units, number of samples to take and how to stratify the tree. Insect habitat influences the selection of the sampling unit, while numbers of samples to take and tree stratification are decided according to information about the insect, management practices and tree physiology. The habitats investigated in this study were leaves, blossoms, fruit, bark and the air. The orchard layout had no effect on the number of within-tree samples to take.

Table 3.2: Number of trees to sample in the preliminary sample for 10 orchard layouts.

Orchard Number	Cultivar	Rows	Total No. Trees	No. Shelter Trees	Advice as trees per cultivar block
1	Gala	4	140	6	2
1	Cox	4	140	6	2
1	Gala	4	140	41	2
1	Brae	3	105	39	2
2	Brae	5	175	43	2
2	Cox	3	105	6	2
2	Brae	5	175	10	2
2	Cox	3	105	39	2
3	Red Deli	4	116	8	3
3	Sturmer	7	203	14	3
3	Brae	2	-	-	-
4	GR	8	185	7	2
4	Cox	8	116	20	2
4	Golden Deli	8	91	14	2
5	Red Deli	5	55	-	2
5	Sturmer	3	33	-	1
5	Jonathan	1	11	-	1
5	Sturmer	3	33	-	1
5	Jonathan	1	11	-	1
5	Sturmer	3	22	-	1
5	Brae	1	11	13	2
5	Kidd's	2	30	-	2
6	Gala	7	182	7	3
6	Cox	5	85	-	3
6	Sturmer	10	170	10	3

Table 3.2 (contd.): Number of trees to sample in the preliminary sample for 10 orchard layouts.

Orchard Number	Cultivar	Rows	Total No. Trees	No. Shelter Trees	Advice as trees per cultivar block
7	Gala	4	100	32	2
7	Brae	4	100	8	3
7	Gala	3	75	8	2
7	Cox	4	100	8	2
7	Gala	4	100	6	2
7	Cox	5	125	34	2
8	Sturmer	2	74	37	2
8	Red Deli	2	86	4	3
8	Gala	2	86	4	3
8	Brae	2	80	4	3
8	Stateman	1	40	2	2
8	Sturmer	1	33	33	2
9	Sturmer	4	72	24	2
9	Gala	4	72	8	2
9	Red Deli	4	72	8	2
9	Cox	4	72	8	2
9	Sturmer	4	72	8	2
9	Gala	4	72	8	2
9	Red Deli	4	72	8	2
9	Cox	4	72	24	2
10	Granny	4	152	44	3
10	Sturmer	4	152	8	3
10	Red Deli	3	114	42	3

<u>Figure 3.7:</u> Between-tree decisions for each cultivar in the preliminary design.

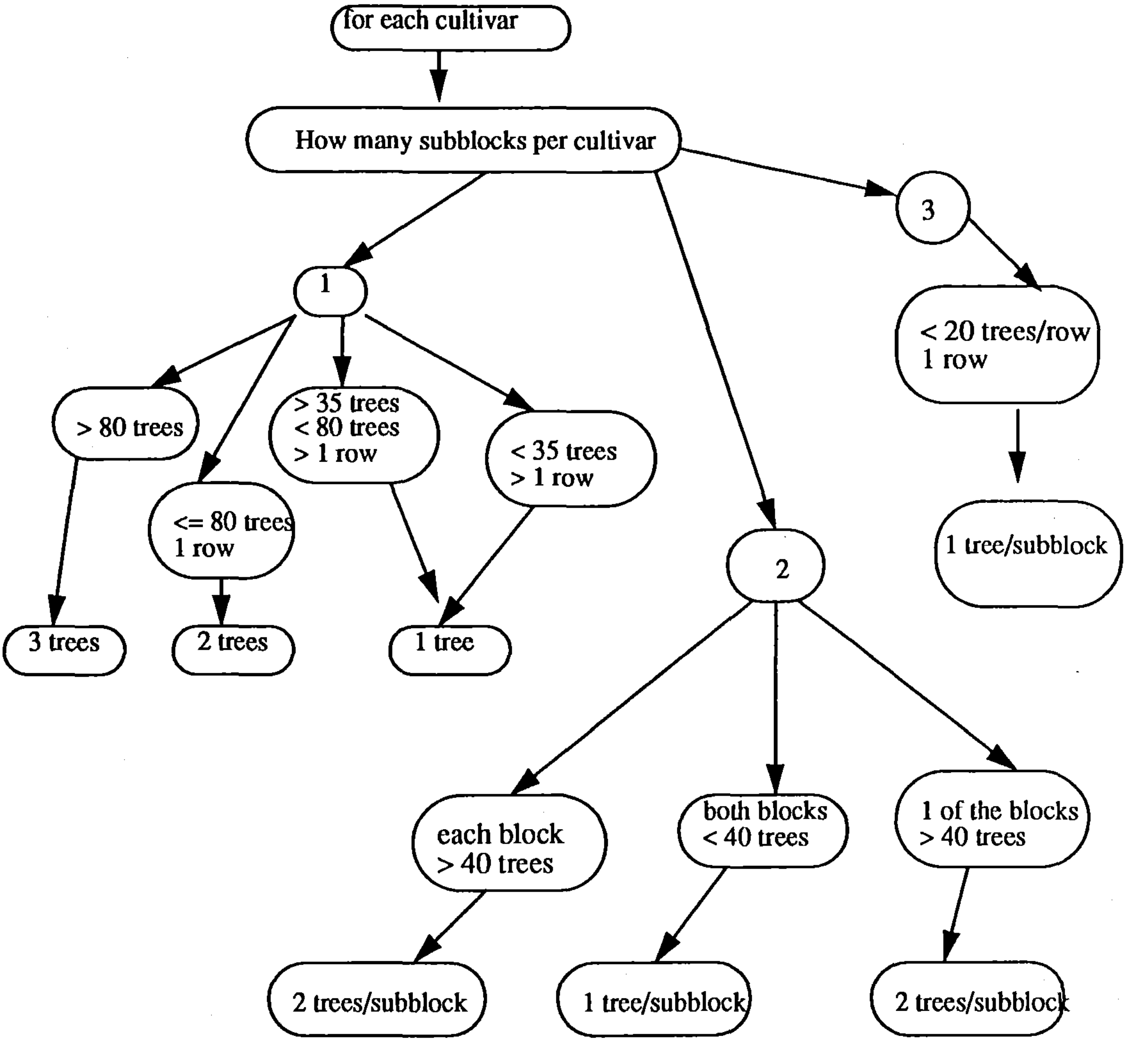


Figure 3.8 shows the decision tree that was extracted from the interviews with the expert. This decision tree represents the decisions to be made if nothing is known about the insect's within-tree preferences. First the expert decides on the strata subdivision, then a decision is made on how many samples per stratum to take. Leaf and blossom clusters rather than single leaves were selected because of the apple tree physiology. Leaves on apple trees grow in a cluster with about 10 to 15 leaves per cluster (Tomkins 1983). Fruits are sampled singly, with numbers sampled depending on whether or not the sampling method is destructive. If sampling is destructive, fewer fruit must be sampled.

Sampling flying insect adults is a special case that is independent of study block layout, because a set number of traps is used per cultivar subblock.

The interviews with the expert also showed that the overall size of the study block and the number of physically separated study areas influenced the preliminary sampling plan. However, these characteristics were not further investigated.

(c) Methods and results for the main sample design

Methods

To generate hypothetical test cases for the main sample design, insect sampling plans were generated from the preliminary design module of the expert system prototype. Cases used to investigate the preliminary design were used for this purpose. The resulting advice on how many trees to sample and how to subdivide the tree was then used, along with the insect preference characteristics, to generate simulated sampling data.

These simulated data sets, in conjunction with a plan of the orchard and other information pertaining to the insect and the sampling methodology, were then presented to the statistician. Again, the interviews were audio-taped, transcribed and analysed.

Orchard 6 (Figure 3.9) illustrates the method followed. The preliminary design module advised sampling three trees per cultivar. Within-tree subdivision in the preliminary sample was always eight divisions (two height strata and four aspect). For an insect living on leaves, the advice for the preliminary sample was to take one leaf cluster per within tree stratum (within-tree stratum is a subdivision of the tree). The trees were usually subdivided into the four aspects - north, east, west, south - and into two height strata - top and bottom.. In this example, a total of 72 sample points had to be generated. Minitab's (1988) random number generator and MLP's (1980) model-fitting function were used to generate the data. The expert was presented with the raw data, means and variances for cultivar, aspect and height strata and, when possible, an analysis of variance (see Appendix 4 for a sample data set).

The first set of hypothetical test cases for the main sample plan design simulated distributional (Poisson, uniform, negative binomial), cultivar (yes/no), strata (yes/no) and orchard position (yes/no) preferences of the insect. The same orchard plan (orchard 1, Appendix 3) was used throughout this set of test cases.

To simulate the distributions, a mean between 0.5 and 3.0 was randomly chosen for each test case; additionally for the negative binomial distribution a k-value was specified. Whenever the plan specified 'yes' for a particular characteristic (e.g., cultivar yes), the mean was doubled before generating the relevant data points. When an outlier was specified (second set of simulated test cases), a data point was randomly chosen and the number at this data point replaced with a number 10 times higher than the highest number in the data set.

Figure 3.9: Orchard layout 6

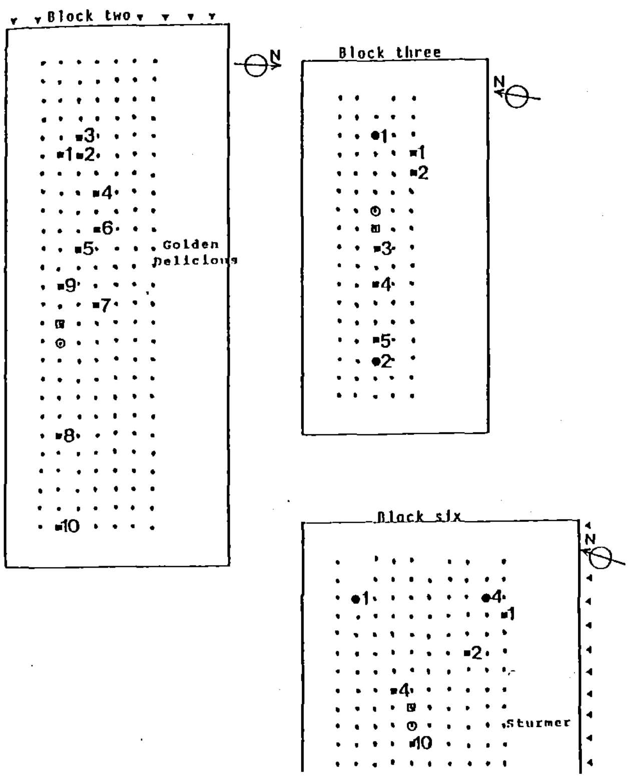
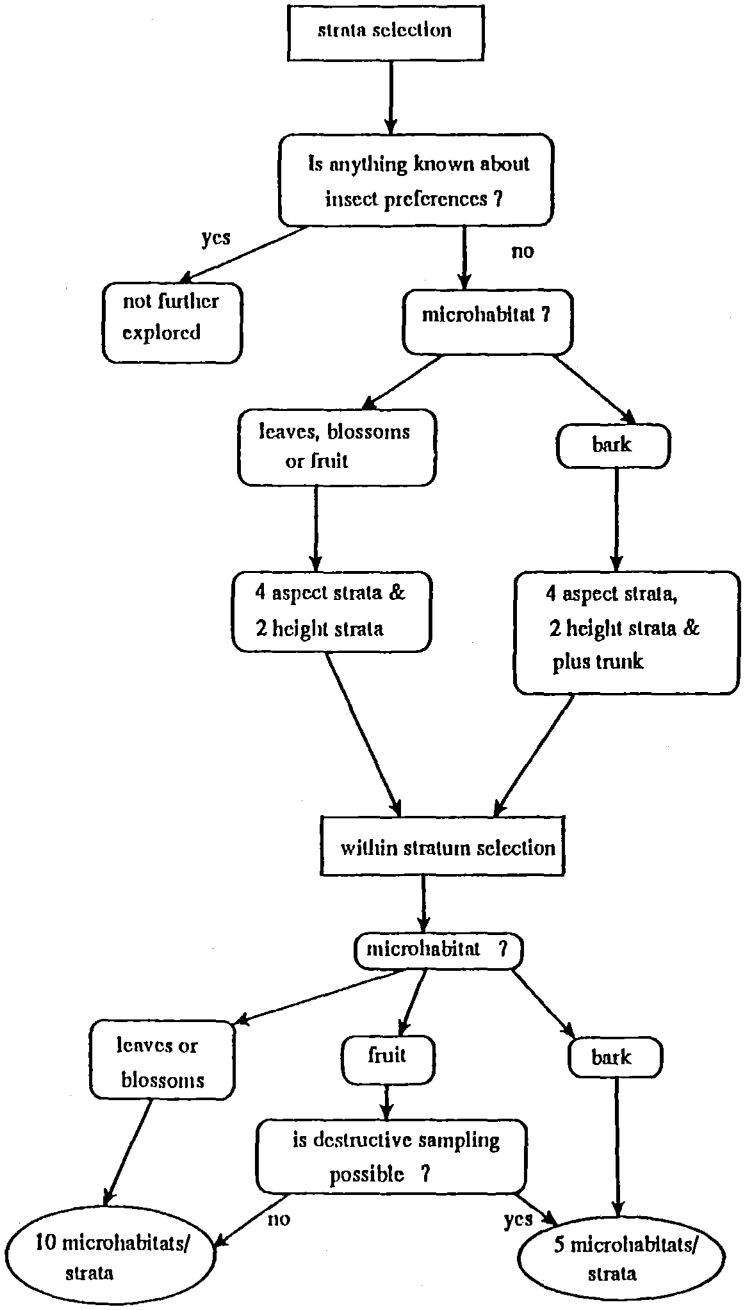


Figure 3.8: Strata selection and within strata decisions.



If viewed in terms of experimental design, the first set of test cases could be viewed as a 3 * 2 3 factorial experiment. A factorial design allows the simultaneous investigation of the effects of a number of different factors over some predesignated range covered by the levels of the factors used in the experiment (Cochran and Cox 1957). Usually different combinations of factors are repeated in different blocks.

Table 3.3 shows the experimental plan followed. Instead of using a full factorial design, only one of the replications was carried out initially. Two reasons influenced this decision. First, time constraints by the expert did not permit the presentation of all 24 cases; second when presenting all 24 test cases, their variations would have soon become predictable, resulting in biased answers. It was hoped that the presented cases would cover the characteristics sufficiently to either not need further test cases or alternatively pinpoint the knowledge that was lacking and to be able to reduce the number of test cases.

The second simulated data sets both took into account some lessons learned during the presentation of the first set and investigated the effect of different orchard layouts. During presentation of the first set, the expert commented that it was not uncommon for outliers (i.e. very large values) to occur. The effect of cultivar and distributional preferences also needed further investigation. Only negative binomial and Poisson distributions were investigated, because they are the most likely distributions to describe an insect's distribution in space.

The distribution of an organism in space can be described by several mathematical models. Insects tend to aggregate in space or are randomly distributed, rarely are they distributed regularly. The negative binomial distribution has often been used to describe insects with a contagious (i.e., clumped) distribution, while a Poisson distribution can be used to describe an insect with a random distribution (Southwood 1976).

The creation of the sampling plan followed the method described above. Table 3.4 shows the plan followed.

Table 3.3: Experimental plan for the generation of the first set of hypothetical test cases for the main sampling plan design.

Case	Distribution	Strata	Cultivar	Position
1	negative binomial	yes	no	no
2	negative binomial	no	yes	yes
3	Poisson	no	yes	no
4	Poisson	yes	no	yes
5	uniform	no	no	yes
6	uniform	yes	yes	no

Note: orchard 1 (Appendix 3) was used for all cases.

Table 3.4: Experimental plan for the generation of the second set of hypothetical test cases for the main sampling plan design.

Case	Distribution	Outlier	Cultivar	Orchard
1	Poisson	no	no	2
2	Poisson	yes	yes	3
3	Poisson	no	no	4
4	poisson	no	yes	2
5	negative binomial	yes	no	3
6	negative binomial	no	yes	2
7	negative binomial	no	no	4
8	negative binomial	yes	yes	3
9	Poisson	yes	no	4

Note: see Appendix 3 for the layout of orchard 2-4.

Results

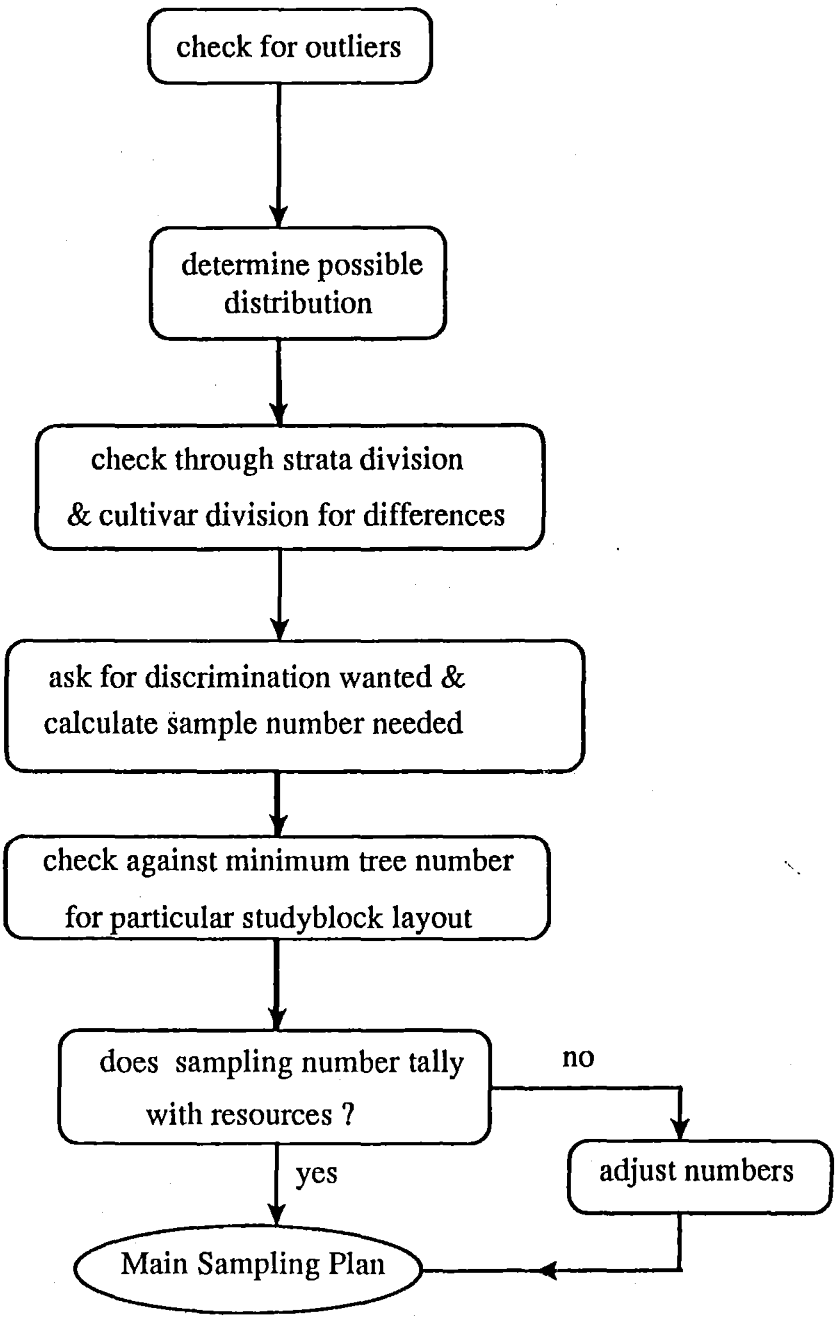
Main sampling plan design decisions differ from preliminary sampling plan decisions. Besides making between and within-tree decisions, the statistician also examines preliminary data for distributional characteristics and possible outliers (i.e., any data that are unusually large or small). Furthermore, the statistician needs to ascertain the level of discrimination that the client wants and whether the time available is compatible with numbers of samples needed to satisfy the level of discrimination desired. Minimum number of trees for a certain size of study block must also be taken into account. Figure 3.10 summarizes this process.

Checking the data for possible outliers is the first step in the decision process for the main sampling plan design. Interviews with the statistician showed that an outlier may be a simple transcription error or may reflect a biological occurrence in the field. In the latter case, the statistician advised repeating the preliminary sample to see if the outlier recurred. If the outlier is a repeatable phenomenon, this point can either be discarded or incorporated into the design. Thus, dealing with outliers is a very difficult problem.

Choice of sampling distribution influences the formula used to calculate the overall sample number needed for a specified precision. In this experiment, the statistician used the proportion of zeros per data point to decide whether the data followed a normal or negative binomial distribution (Figure 3.11).

The advice for the first set of hypothetical test cases was the same. The number of trees to sample per cultivar was 20 trees, except in case 5 where the statistician advised sampling 30-40 trees. The within-tree subdivision followed the rules established for the preliminary design, except in case 4 where the statistician suggested discarding the height division (Table 3.5).

Figure 3.10: Decision process for the main sampling plan design.



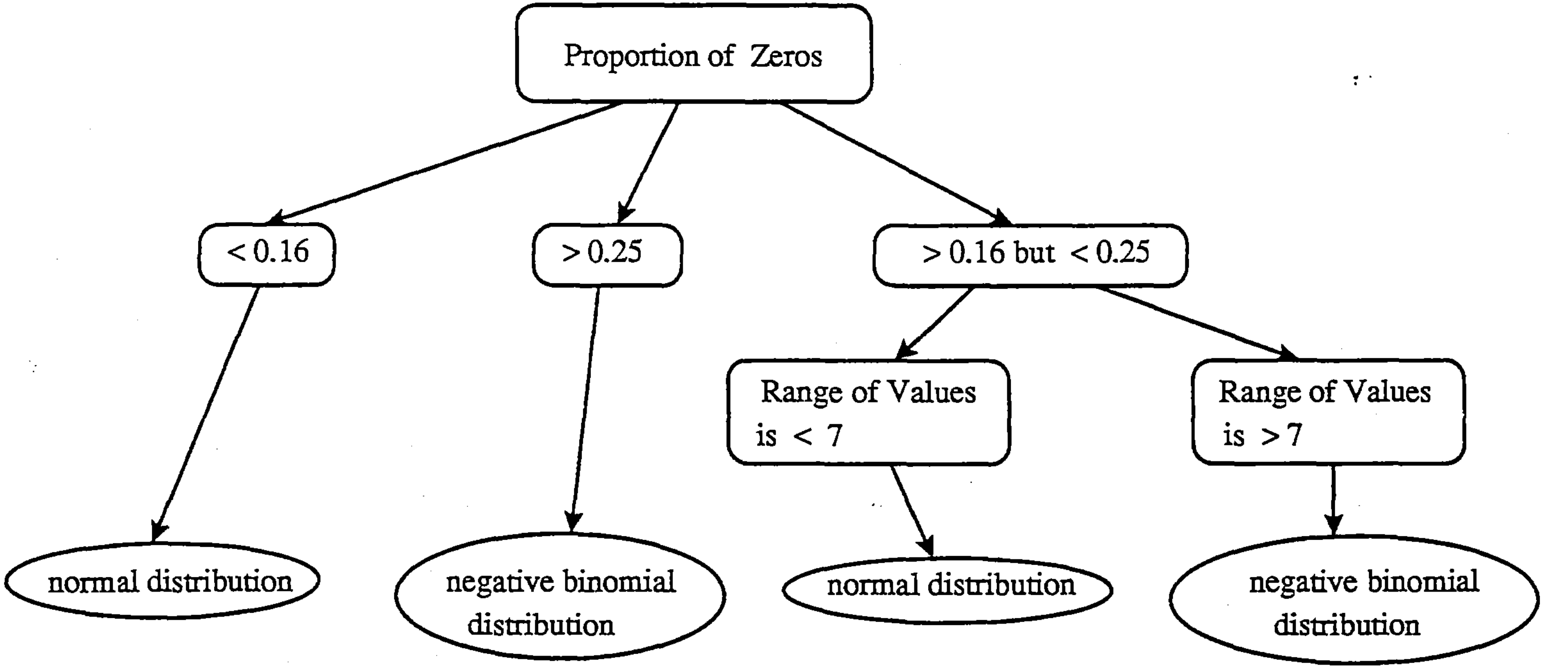


Figure 3.11: The influence of the proportion of zeros on sampling distribution

Table 3.5: Results for the fisrt set of simulated test cases

	case 1	case 2	case 3	case 4	case 5	case 6
Number of Trees	20	20	20	20	30-40	20
Strata Subdiv. as for Prelim.	yes	yes	yes	no	yes	yes

Table 3.6 shows the results for the between-tree decisions for the second set of hypothetical test cases. Figure 3.13 (see next page) shows the resulting decision tree.. Note that the deciding factor is tree number per cultivar subblock. The test cases covered the domain sufficiently.

Selecting the trees from which the insect is sampled is part of insect sampling plan design. Usually the statistician indicates to the entomologist some general principles to be followed when selecting the actual tree, i.e., the statistician advises the entomologist which trees to exclude from the pool of possible trees to sample. Commonly all trees on the edges of a block are excluded, however, if the block has too few rows and/or is situated on the outside, some of the edge rows may have to be kept (see Figure 3.12 for the decisions involved).

Figure 3.12: Decisions on which edge rows to discard

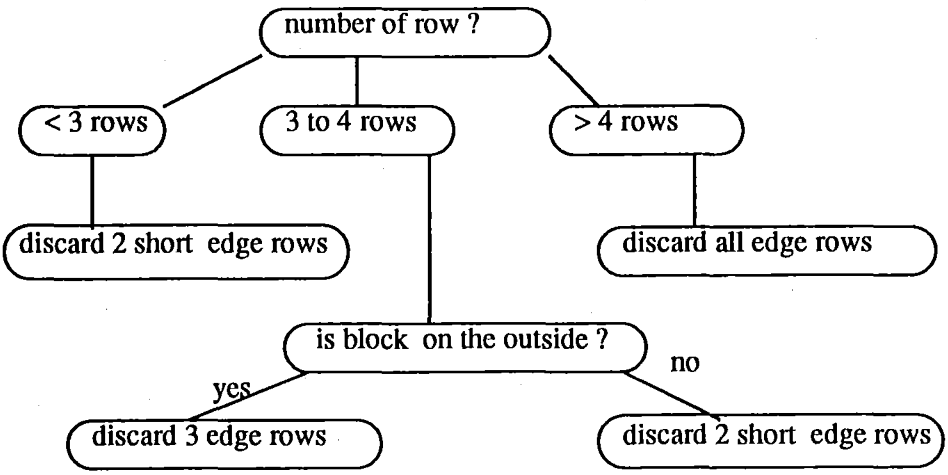


Table 3.6: Number of trees to sample for the second set of simulated test cases for main sample plan design.

Case	Orchard	Cultivar	No of subblocks	Rows	Trees/Row	No. Trees	Minimum No Sampled
1	1	S	2	4	18	72	10
		G	2	4	18		10
		RD	2	4	18		10
		CO	2	4	18		10
2	8	ST	2	2/1	42	84/42	15
		RD	1	2	42		12
		GS	1	2	42		12
		RB	1	2	42		12
		S	1	1	42	42	10
3	3	RD	1	4	29	116	12
		S	1	7	29	203	15
		B	1	2	29	58	10
4	5	KD	1	2	15	30	10
		RD	1	5	11	55	10
		S	3	3/3/2	11	33/22	15/5
		J	2	1	11	11	12
		B	1	1	13	13	10
		KO	1	3	13	39	10
5	10	GD	1	4	38	152	12
		GS	1	4	38		12
		RD	1	3	38	114	10

Table 3.6: Number of trees to sample for the second set of simulated test cases for main sample plan design.

Case	Orchard	Cultivar	No of subblocks	Rows	Trees/Row	No. Trees	Minimum No. Sampled
6	4	GS	1	8	25	200	12
		CO	1	8	15	120	12
		GD	1	8	12	96	12
7	1	G	2	4	35	140	12
		C	1	4	35	140	10
		B	1	3	35	115	10
8	2	B	2	5	35	175	12
		C	2	3	35	115	10

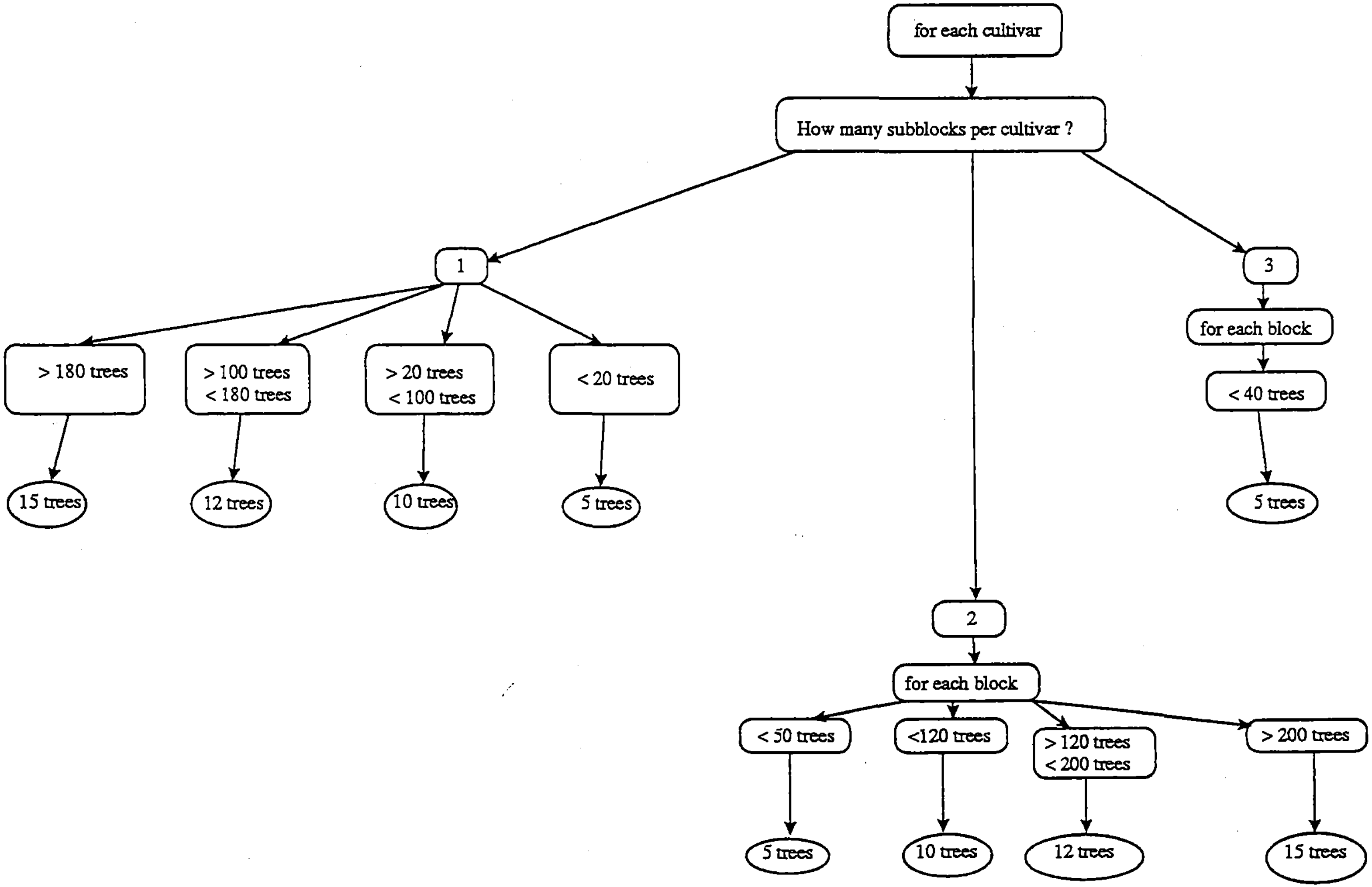


Figure 3.13: Between tree decisions for the main sample plan design.

(d) Summary

To generate test cases in the domain of insect sampling plan design, a method - knowledge acquisition by simulating test cases - was developed. The method relies on the idea that people when making decisions choose among alternatives (Tversky 1972). These alternatives can be presented in an interview in a manner that is similar to that for the experimental method.

The characteristics most likely to influence the choice of sampling plan were determined. The choice of preliminary sampling plan design was investigated with a standardized form. This form, developed from the initial checklist (a useraid), is a list of questions, the answers to which provide the statistician with the necessary information to design a preliminary sampling plan.

To elicit choices made in the main sampling plan design, hypothetical data sets were generated by using the preliminary design expert systems prototype to generate the number of samples for a particular study block layout. Two statistical packages (MLP and MINITAB) were then used to randomly generate the actual numbers. It was during random number generation that certain characteristics (distributional and preferences) of the insect were modelled.

The use of this technique resulted in decision trees that could be easily converted into a rule-based expert systems prototype. The technique helps to standardize the interviews and the knowledge elicited. Characteristics that did not influence the choice of sampling plan could be easily identified.

Knowledge acquisition by simulation uses example cases to generate decision trees. Quinlan (1986) discussed, in the context of machine learning, shortcomings that are associated with this approach.:

1. The case studies presented may contain redundant information or may not include uncommon cases.
2. Not all attributes, that are used to distinguish between classifications may be known or attributes may be based on subjective judgement or measurement. Both problems may result in missclassification.
3. Selected attributes may not distinguish sufficiently between classifications.
4. A fundamental weakness of this approach is that except for special cases the decision tree can

not be completely validated.

5. Cases must be carefully selected to cover the entire problem space.

However knowledge acquisition by simulation differs from a machine learning approach in one crucial aspect: the expert is used to discuss the limitations and errors that may occur in any decision tree. While some of the above shortcomings may still occur, especially not including uncommon cases, the presence of an expert ensures that they are minimized.

Knowledge acquisition by simulating test cases could be easily adapted to other domains to generate test cases from case histories or other data and to standardize the presentation of test cases to the expert. However, the generation of the actual hypothetical test cases may vary from domain to domain. This technique could also be useful for integration of the knowledge of several experts or validation of the expert system.

CHAPTER 4

Characterising advisory interactions between statisticians and entomologists

4.1 Introduction

Developers of expert systems have had some success in modelling the problem-solving role of human experts, but have placed little emphasis on the expert's function as an advisor. An advisor not only provides a solution to a problem, but also makes the solution meaningful and accessible and is responsive to the user's needs (Coombs and Alty 1980). In human-human interaction, this process is mediated through human language. In human-computer interaction it is mapped onto the user interface (Chignell et al. 1989). Kidd (1985) suggests that two of the major shortcomings of current expert systems are their rigid dialogue structure and inadequate explanation facilities. In comparison, Kidd (1985) found that naturally occurring consultations between experts and their clients included:

- different types of user questions,
- cooperative problem-solving between expert and user, and
- explanations to enhance the user's understanding of the domain.

A common procedure in the building of expert systems is to present experts with test cases and to observe the expert's problem-solving behaviour. However, few reports on the observational procedures necessary to capture the advisory behaviour of experts are available (but see Coombs and Alty, 1980 and Belkin, 1987). Clearly, the role of an expert in many areas involves both a problem-solving and an advisory role. In the problem-solving role, the expert supplies a solution to a problem, while in the advisory role the expert guides the client's decisions and supports the user in finding a solution to the problem.

The advisory role of an expert is often fraught with difficulties. Coombs and Alty (1980) investigated face-to- face guidance of university computer users, and reported serious shortcomings in the advisor-user interactions. Inexpert users criticized the advisors for failing to make the information they gave meaningful, and also criticized the advisors as being unsympathetic to their needs. By collecting information on an advisory interaction, reasons why communication problems occur in such interactions might be addressed.

To gain an understanding of the advisory role of an expert, we must investigate the interaction between the expert and the client in an advisory situation. We need not only a model of the expert's problem-solving process, but also a model of the interactions between the expert and the client. A combination of both these models or representations can then be the basis for a more accurate simulation of the advisor-client interaction. If shortcomings are observed in the advisor-client interaction, the model of the interaction can then be used to pinpoint the difficulties.

4.2 Related work on observational studies

4.2.1 Introduction

Caroll and McKendree (1987) provided an overview of interface design issues for advice-giving expert systems. They drew attention to a number of design issues that are in need of investigation. These issues include the types of advisory strategies used, modelling of different levels of user expertise, and the need for further development of observational methods used to investigate advice and advice- giving systems.

Observational studies have been used in expert systems research for knowledge acquisition (Belkin [1987] investigated human-human interaction in information retrieval situations), and to explore the dynamics of advisor-client interactions (Coombs and Alty's [1980] exploration of face-to-face guidance of computer users).

Observation of human-human interactions can also be used as a model for human-computer interactions when the user interface is designed. We assume that humans would want to interact with computers as they interact with people, and that the way people interact is the best way to interact. Pollack et al. (1982) recorded and analysed dialogues from a radio call-in show; these were used to predict how expert systems should respond to queries. Ochsman and Chapanis (1974) tested human communications when solving problems in ten different modes (i.e., typewriting, handwriting, voice and combinations of these) in order to determine the modes that computers should use in interactions with humans.

Observation of human-human or human-computer interactions is part of empirical studies in psychology, human-computer studies, linguistic and occasionally expert systems research. A search of the literature revealed only one example of the use of observational methods in empirical studies of the statistical consulting process. Hand (1984) described a series of studies of audio-taped statistical consultation sessions. The purpose of his study was to show how the strategy used by the statistician was similar to the one used by the medical consultant. The study was not empirical (i.e., the interactions did not seem to be transcribed or analysed in any organized manner). This lack of experimental design probably explains why Hand concluded that the strategic pattern was not always easy to discern through the intricacies of human interaction. He did conclude, however, that the strategy used seemed to fit the hypothetico-deductive method.

In empirical studies involving the observation of human- human interactions, the interactions are usually tape- recorded and then transcribed. Discourse analysis is a method that can be used to analyse these recordings. It is a very large field and can be used for socio-, psycho-, or computational linguistic purposes (Brown and Yule 1983). Sociolinguistic discourse analysis is concerned with the structure of social interactions that manifest themselves in linguistic situations verbally. This type of analysis seeks to explore the dynamics of a given linguistic interaction and develop some system for describing it. Labov and Fanshel (1977) provided an example in the field of psycho- therapy. Psycholinguistic discourse analysis deals with issues of language comprehension in written texts. The purpose of computational discourse analysis is the production of models of discourse processing (using short texts constructed in a highly limited context).

4.2.2 Review of some aspects of discourse analysis

In the 1970s linguists recognized that language studies should not be restricted to the grammatical analysis of abstract language systems (Van Dijk and Kintsch 1983). Socio-linguists became increasingly interested in everyday conversational interactions. Schlegloff and Sacks (1973) state that their interest in conversational materials stems not from a special interest in language but that they see discourse analysis as the first step towards an observational discipline that describes details of social interactions in an empirical, yet formal and rigorous way.

One of the basic characteristics of conversations is turn- taking (i.e., speaker and listener reverse their roles). Few speech overlaps or silences occur (Coulthard 1977). These turns or utterances are commonly used as the units for analysis of the discourse structure. Discourse analysis then involves audio-taping conversations, transcribing these (using transcription protocols - for example those based on Jefferson-Sacks et al. 1974) and then dividing the utterances or turns (the units of analysis) into episodes and sub-episodes. Episode and sub-episode constitute the structure of the dialogue, if any structure is present.

Although it was initially used to analyse everyday conversations, discourse analysis has also been used in empirical studies concerned with task-oriented conversations. For instance, Belkin (1987) followed the strategies outlined by Grosz (1978) for analysis of task- oriented dialogues. Grosz and Sidner's (1986) theory on discourse analysis (an extension of her theory on analysis of task-oriented dialogues) stresses the role of purpose and processing in discourse units. Rather than drifting from topic to topic, as is common in everyday conversation, task- oriented dialogues have a definite goal or purpose. Grosz contends that this is true for all dialogues, albeit sometimes more covertly. In a practical application of this type of discourse analysis reported by Guindon (1988), the task structure was derived using task analysis, which formed the basis of the subsequent derivation of the discourse structure.

Task analysis is a technique that identifies the constraints and possibilities inherent in performing a particular task and results in a task structure (Guindon 1988). The aim of task analysis is to identify the objects and the operators involved in performing a task, and to identify the sequence of operators which produce a task sequence

In their investigation of face-to face guidance of university computer users, Coombs and Alty (1980) were interested in identifying the interactive goals of the participants. They followed a method proposed by Mathiot (1978), who views conversations as governed by social objectives. In this context an analysis of face-to-face interactions was considered as valid only in terms of the participant's objectives.

Coombs and Alty's (1980) research revealed deficiencies in this type of encounter. They also found a simple three-part structure to the interaction. Their adaptation of Mathiot's method involved obtaining a functional description of an interaction. Sample interactions are recorded and the participants are questioned on the perceived structure of the recorded interaction. The latter becomes what these researchers termed a 'frame of reference'. This 'frame of reference' helps to distinguish between relevant and accidental structures. Analysis of the transcripts gives information on the activities performed by the participants and the relationship between the participants.

Mathiot's and Grosz's methods have similar outcomes: they result in a subdivision of the interaction into episodes (Mathiot 1978) or functions performed (Grosz 1978). However, the two methods have differing theoretical bases. Grosz(1978) postulated that the task structure hierarchy imposes a similar hierarchical structure on the sub- dialogue. Mathiot (1978) viewed conversations as cultural events, while Grosz and Sidner (1986) focused on discourse structures and their computational representations.

The author followed Mathiot's method because it has been previously applied in a similar experimental setting. Viewing conversations as cultural events may take precedence over Grosz's idea that a task structure hierarchy imposes a similar hierarchical structure on the sub-dialogue, when conversations are actually analyzed.

4.3 Objectives of the study

The purpose of this empirical study was to analyse expert- client interactions in the domain of design of insect sampling plans for the orchard environment. In this field, statisticians advise entomologists on how to design insect sampling plans. Entomologists are expected to have at least a basic grasp of statistics.

The study investigates whether advisory interactions between entomologists and statisticians have sufficient common elements to be regarded as a category of face-to-face encounters. If they are a distinguishable category, then they can be used as a model for computer-human interactions of that domain. Ultimately, this model can then be incorporated in the user- interface of an expert system for insect sampling plan design.

When human-human interactions are used as a model for computer-human interactions, one must be aware that the interactions used to build the model may not represent 'ideal' interactions (e.g., Coombs and Alty 1980). Goals of the participants may not be met or communication difficulties may occur. Hence a further objective was to investigate who controlled the interaction or whether control was shared by the participants. Overwhelming control of the interaction by one participant may be an indication of communication difficulties between the participants. The statistical community (e.g., Hunter 1981; Dirlich et al. 1987) has viewed the statistician-client interaction in principle as a cooperative undertaking.

4.4 Methodology and Analysis of transcripts

4.4.1 Introduction

Several techniques (i.e.,verbal protocol analysis, interviews and observational studies) are available for use in empirical studies of the present type. However, interviews about advisory interactions would not have been appropriate for this type of empirical study, because they cannot reproduce the detailed context of 'real' behaviour (Belkin et al. 1987). Introspection and recollection are known to be biased, in terms of implicit expectations about outcomes, or a priori judgements about the extent to which a particular occurrence is a plausible cause of a given response (Nisbett and Wilson 1977). Verbal protocol analysis requires that the expert thinks aloud while carrying out the task in question. Again, verbal protocol analysis is an inappropriate technique for this context. Observational studies seek to study expert behaviour at work on real problems in the expert's real environment (Belkin et al. 1987). A form of observational study was used to investigate the interaction between statisticians and entomologists in the domain of insect sampling plan design. Coombs and Alty (1980) viewed conversations as an information flow between the participating individuals. In this context, conversations can be seen as containing two groups of variables:

- those concerned with the content of the information transfer and,
- those concerned with the control of information transfer.

The analysis of the interactions then falls into two categories:

1. Analysis for the content of the information transferred. This is a functional analysis that attempts to find the underlying macro- and micro- structure of the conversation. The macrostructure refers to the broad meanings or functions communicated, while the microstructure refers to the structure perceived within the macrostructure. The analysis for information content is mainly qualitative.
2. Analysis for the control and flow of information transfer, to ascertain who controls the conversation and the information flow and what form the information flow takes. This analysis is mainly quantitative.

Usually, observational studies involve observing and recording the behaviour of the participants in their normal environment as unobtrusively as possible (Belkin et al. 1987). Both Coombs and Alty

(1980) and Belkin (1987) collected audio-tapes of natural conversations in this manner. This was not the case in this empirical study, as the number of naturally-occurring interactions between entomologists and statisticians was limited, by the relative rarity of insect sampling plan design problems in a country the size of New Zealand. To overcome this problem, an experiment was designed involving graduate students who acted as entomologists. The students brief was to seek advice from statisticians on a pre-defined problem in the chosen domain (the insect sampling plan design for the orchard environment).

Because observational studies are very time-consuming to perform and analyse, only eight interactions were collected. Other studies involving face-to-face interactions report a sample size of between seven and 19 recorded interactions. Grosz (1978) used 19, Coombs and Alty (1980) and Labov and Fanshel (1977) used 14, and Belkin et al. (1987) used seven recordings.

4.4.2 Subjects and Materials used

(a) Subjects

Each of eight participating entomology students (four graduate and four honours) were available to visit one of the four participating statisticians. All statisticians were familiar with insect sampling plan design problems, because they were required to advise on this kind of problem as part of their work. Each statistician was visited by two students on separate occasions. All statisticians were male. Five students were male, three were females. Male-female miscommunication (Maltz and Borker 1982)) is known to occur, but it was not possible to arrange a single-sex empirical study. All students had basic knowledge of statistics, and were also provided with a brief essay (Appendix 5) on the principle of insect sampling plan design to ensure that all participants had a similar grounding in the domain. Socio- cultural factors such as differing discourse strategies are recognized as major variables in face-to-face encounters (Gumperz 1982). All interactions were mono-cultural to avoid introducing additional variations (i.e, participants were white anglo-saxons).

(b) Materials

The students were provided with the following materials before the interaction:

- An essay explaining the principles of insect sampling plan design (Appendix 5).
- A scenario asking them to imagine that they had been appointed to the position of a research entomologist and that their first assignment was to get statistical advice on a particular insect sampling plan design problem (Appendix 6).
- One of two available orchard layouts (Appendix 7).
- A tape-recorder to record the interaction.

The students made their own choice of orchard pest species to ensure that they possessed sufficient knowledge about it. The statisticians were briefed on the objectives of the experiment and the procedure to be followed by the students. They were asked to treat the students as if they were clients.

(c) Data transcription

All tapes were transcribed using a transcription protocol based on G. Jefferson (Sacks et al. 1974, Appendix 8). The transcripts were divided into utterances as units of analysis. An utterance is a speech sequence by one participant during the conversation, which is completed when the other participant takes a conversational turn (Belkin et al. 1987). Both the transcript and the division into utterances were checked by a trained linguist.

4.4.3 Experimental procedure

(a) General comments

Mathiot (1978) indicates the need for a 'psychological reality' in order for an analysis of face-to-face interactions to be relevant. The idea of psychological reality refers to the event as viewed by the participants, rather than as viewed by an outside observer. Basing the analysis on the way in which the participants perceive it means that their psychological reality becomes part of the analysis. To fully analyse a face-to-face interaction, we need a specimen of an interaction, i.e., an audio or video tape-recording of a particular face-to-face interaction and a verbal report about the interaction by the participants. Verbal reports can be separated into three categories: recollections, immediate recalls and blow-by-blow commentaries.

(b) Initial method

Mathiot's (1978) method as used by Coombs and Alty (1980) consists of audio-taping the conversation and debriefing the participants about the interaction shortly after the event.

With the first two interactions this method was followed. There were two debriefings per participant, the first occurring immediately after the event. The student was asked to repeat her/his questions and to recall answers given. The statistician was asked to comment on the interaction and to rate the perceived expertise of the user on a five-point scale. A second debriefing was held when the transcripts of the conversation were available. Each participant was asked to comment about expectations and attitudes towards the actual interaction. Finally each participant was asked to group the text into episodes. The questions posed to the statistician centred around his understanding of the user's question, the reason behind the solution and the assessment of the user's understanding of the solution. The student was questioned about comprehension of advice received and attitude towards the adviser. This second debriefing session was also audio- taped.

(b) Problems encountered

This method of debriefing had various shortcomings. Transcribing the various debriefing sessions was unreasonably time-consuming (e.g., a one hour tape recording would take about 15 hours to transcribe). Participants, especially statisticians, seemed to feel threatened by the task of grouping the text into episodes and often tried to justify their advice instead. Furthermore, leading questions were difficult to avoid and participants had to switch between modes (seeing written text and responding verbally).

(c) Adjustments to the method

The technique was therefore simplified. The transcripts were returned to the participants with a written explanation of what further action was required of them (Appendix 9). They were asked to read the transcript twice. In the first reading, they were to label groups of utterances (the microstructure) and in the second reading organize and label these into larger groups (the macrostructure). This technique was used for the remaining six interactions. It proved more efficient and avoided mode-switching, and leading questions, and can be considered an extension to Mathiot's (1978) general framework.

4.4.4 Analysis of transcripts

(a) Analysis for information content

Each interaction was analysed separately by the author and an independent third person (as above). These analyses were then compared with the macro/micro structures perceived by the participants. Each interaction should yield four structures (i.e., two as perceived by the participants, one from the author of this study, one from the independent observer) that could be compared for similarities. The objective of this analysis was to determine whether the interactions were a definable class of conversational interactions with a discernible structure.

(b) Analysis of information control

The issue of roles played by the participants and the question of who controls the conversations was investigated by viewing utterances as adjacency pairs (Schegloff and Sacks 1973). All interactions were coded into pairs of the type question-answer (Q/A), and statement-statement (S/S). A note was also made of utterances that did not fit into either category. Each of these pairs was defined as described by Coombs and Alty (1980). The participant who asks for information (Q/A), counters information given by the other participant (S/S) or initiates an adjacency pair, controls the information flow (Schegloff and Sacks 1973).

The reliability of the scoring was tested by having a second person score all conversations. Reliability of scoring is usually assessed by computing the proportion of cases in which the raters agree. No formal criteria exist for determining if reliability is sufficient; in practice a score above 90% is desirable (Kail and Bisanz 1982), but values as low as 75% (Biggs and Mock, 1983) are acceptable.

As per Coombs and Alty (1980), counts of the two types of adjacency pairs were taken and who controlled each pair was noted. The scores for the participants were then expressed as a percentage of the total number of relevant pairs per conversation. The hypothesis that the overall conversation, the question/answer pairs and the statement /statement pairs were controlled by the statistician was tested with the Wilcoxon matched-pairs signed rank test (Siegel 1957). Appendix 10 provides a sample interaction and a sample analysis of this interaction.

4.5. Results and discussion

4.5.1 The structure of the interaction

(a) Overview

The aim of the qualitative analysis of the transcripts was to determine whether the eight recorded interactions belonged to a definable class of conversational interactions and to determine the structure of this class of interaction.

Mathiot (1978) suggested that conversations be viewed as cultural events. The participant's perceptions of these cultural events then becomes central to the analysis. However, the participant's perceptions of the interactions proved disappointing (Appendix 10d for sample perceptions). First, not all participants completed this part of the study. While all the participating students complied with the requested procedure (eight perceptions), three out of eight statisticians perceptions are still uncompleted. Second, participants had also been asked to subdivide interactions into macro and mirco-structures (episodes and sub-episodes). Again, not all participants (eight out of 13) complied with this request, and instead subdivided the interactions into sub-episodes only (Table 4.1).

Table 4.1: Number of outstanding perceptions and number of perceptions received that were not subdivided.

	Students	Statisticians
Total no. of perceptions expected	8	8
No. of perceptions received	8	5
No. of perceptions received & subdivided according to instructions	3	2

It was hence decided not to use the participants perceptions of the interactions directly in the analysis. With hindsight, asking participants for their perception may have been an unreasonable request. Mathiot (1978) developed her method to describe everyday face-to-face interactions, such as playing cards or hitch-hiking. In contrast, the experiment described here was dealing with a work situation. Time constraints and inability on the part of the statisticians to transcend their own role may have been the reason for the three statisticians perceptions not being completed. In addition the roles of the participants and the goals of the interaction were preset (as it was a simulation). Under simulation conditions, one can probably not expect the participants to comment on roles and goals because they had no choice about either factor. However, this part of the method was not crucial to the overall analysis of the interaction and the study was completed successfully without it.

Overall, the available material showing participants perceptions did support the observer's analysis of the overall structure of all interactions. Perceptions that were subdivided into macro- and microstructures (five out of 13, Table 4.1) by the participants mirrored the subdivisions found by the observers fairly closely. Out of the remaining eight perceptions, four were in parts similar to the observer's subdivisions (Appendix 10c and 10d for a sample of the observers and the participants' perception).

All interactions could be analysed into three episodes: information collecting, advice giving and closing. One would normally expect greeting to be the first stage of this type of interaction, but the participants were usually introduced to each other by the author and tape-recordings were not started until after this introduction. Two of the eight interactions have this simple linear structure, while the remaining six interactions show interchanging between collecting information and giving advice. This interchanging among episodes indicates a refinement of the advice as the statistician collects more information. Statisticians writing about statistical consulting have commented on the iterative nature of the process (Hunter 1981, Jockel 1986).

The interaction can be described by the following model:

1. Information collection
    a. Problem statement
    b. Collecting information on the insect, the orchard, resources available, precision required, sampling methods, history and others

2. Advice giving
    a. General statistical issues
    b. Actual sampling plan or part of it
    c. Data analysis

3. Closing

This model of the statistician-client interaction is based on empirical data and is a functional description. Previous descriptions have provided only theoretical (Jockel 1986) or anecdotal (Dirlich et al. 1987, Zahn and Isenberg 1983) models of the interaction. These types of models are quite interchangeable (i.e., Zahn and Isenberg and Dirlich are virtually identical). Zahn and Isenberg's model, for instance, consists of four phases:

1. Identify the relevant aspects of the problem situation.
2. Define the client's goals.
3. Determine actions to be taken
4. Discuss aspects of the consulting relationship: who will do what.

Dirlich et al. (1987) also discerned four phases:

1. Communicate the problem (client).
2. Seek a common understanding and representation of the problem (client and consultant).
3. Search for a strategy to solve the agreed-upon problem
4. Execute plans that lead to solution.

Both of these models describe the consulting process at a more abstract level commonly found in textbooks, rather then reflecting the concrete reality of the process. How the relevant aspects of the problem are identified and what tasks are necessary to identify the client's goal are unresolved. Both of these models are one-sided in the sense that they describe only the statistician's part in the process. The model obtained from the analysis of transcripts of interactions between statisticians and clients complements Zahn and Isenberg's and Dirlich's models because it describes the kinds of tasks that are performed during an interaction in detail.

(b) Information collection - the within-episode structure

All interactions started with a statement of the problem as perceived by the entomologist. Typical examples were:

1. 'The insect we are interested in is called Froggats apple leafhopper, and it's not really a pest of apples as such, but it's sort of in the future. Here is a plan of the orchard.'
2. 'The situation is sampling for light brown apple moth leaf roller in an orchard situation. This is quite a complicated insect to sample, I guess, because it has more than one generation a year in Canterbury.'

In all interactions, the statistician then asked a clarifying question about the problem statement, such as:

1. 'So what's the purpose of looking at these things ?'
2. 'What is it you would like to do ?'

This question would mark the start of usually quite a long question/answer information-collecting sub-episode, during this sub-episode the statistician would collect information on three to five items. In subsequent passes through this sub-episode, the amount of information requested had usually shrunk to one or two items (67% of all information requests). The order of information collected followed no common pattern in any of the passes through a sub-episode.. In two interactions, the statistician needed only one pass through the whole information-collecting episode. In the remaining interactions the statistician needed between two and five passes. Similarly, further iterations (between two and ten) were required through the information-collecting sub-episode (Table 4.2).

Interactions fell into two groups. In the first group the statistician was able to ascertain the problem, collect all the necessary information and give the required advice with only one pass through each episode. In the second group of interactions, the statistician had to repeat the various episodes until the problem was sufficiently clarified and enough information was collected to give the required advice.

By the end of the conversation, all statisticians had requested information on the problem, the orchard, the insect and the resources. In two out of six interactions, the statistician had also inquired about the precision required. In half the interactions, the statistician had sought information concerning previous sampling of the insect by other researchers.
The information-collecting episode was characterised by questions from the statisticians that were short and to the point, such as:

1. 'And the eggs are laid on the tree ?'
2. 'Could you tell me what the insect does ?'

The entomologist's responses were more varied in length, depending on how the question was structured.

Table 4.2: Number of passes per statistician through the information-collecting episode.

	passes per statistician						
sub-episode	1	2	3	4	5	6	10
problem statement	2	4	1	1	1	-	1
collecting information	2	1	2	1	-	1	1

Table 4.3: Number of passes per statistician through the advice-giving episode.

	passes per statistician						
sub-episode	1	2	3	4	5	6	11
general statistics	8	1	-	-	-	-	-
sampling plan	2	-	3	-	1	1	1
data analysis	3	1	-	-	-	-	-

Table 4.4: Number of words per statement in 103 advisory statements.

Number of words	1-50	51-100	101-200	201-300	>301
occurrences	24	31	30	11	7

df= 102 chi-square = 55.56 for an expected Poisson distribution

(c) Giving advice - within-episode structure

The advice-giving episode can be subdivided into three sub- episodes: general statistical advice, sampling plan advice and advice on data analysis. Unlike the information- collecting episode, there was no common pattern in which the sub-episodes occurred or the order in which information was requested within the sub-episodes. However, all entomologists came away with a sufficiently detailed sampling plan to begin sampling in the field. Some cycling through this episode was again observed, but it was largely restricted to the sampling plan sub-episode. General statistical comments were made by all statisticians. In seven out of the eight interactions, the statistician passed through this sub-episode only once, and in one interaction twice. In only four out of the eight interactions did the statistician give advice on how to analyse the data. The sampling plan advice sub-episode was completed once in two interactions, three times in three interactions and five, six and 11 times in one interaction each (Table 4.3).

The goal of the interaction between entomologist and statistician was the development of a sampling plan design for a particular orchard and a particular insect. A count of who initiated the sub-episodes on general statistics and data analysis was taken, because these topics were not explicitly part of the objective of the interaction. Eight out of 10 times the statistician initiated an interaction on general statistical topics, while the initiation on data analysis was 50% by a statistician and 50% by an entomologist.

A characteristic feature of this episode was the long monologues of the statistician. When counting the number of words per advisory statement (n=103, Table 4.4), 60% of the statements were between 50 and 200 words, 23% were under 50 words and 17% were over 200 words. This fits a Poisson distribution (Chi-square = 55.56, p>0.05). The entomologist's utterances during this episode were rarely more than 10 words, and most commonly only one word. As the goal of the interaction was to obtain advice, some monologues by the statistician concerned can be expected.

(d) Closing

The closing occurred in all interactions. It was fairly brief and was marked by politeness strategies, as in the following sample:

> Statistician: 'Yeah.'
> Entomologist: 'Alright.'
> Statistician: 'Yeah.'

It would then move on to a more definite closing remark:

> Statistician: 'Good, are there any other questions you want to ask.'
> Entomologist: 'No.'
> Statistician: 'Good.
> '

On some occasions the statistician would also summarize the sampling before closing, or the closing would be marked by the participant's discussing a new but related topic.

4.5.2 Who controlled the interaction ?

(a) Quantitative results.

The aim of the quantitative analysis was to determine who, if anyone, controlled the conversations. Initially it was important to establish whether the reliability (in terms of similarity of scores) between the two persons scoring was sufficient to consider the data at all. The Wilcoxon matched-pairs signed rank test (Siegel 1957) was used for this purpose (i.e. differences between the paired scores are ranked from smallest to largest without regard of the sign; the signs of the original differences are assigned to the rank, the sum of all the positive and the sum of the negative ranks is computed and the smaller of the two is compared with the critical value).

Reliability between the two persons scoring was highly significant when comparing scores for overall control (Pearsons $r=0.86$, $p<0.01$) and for question/answer pairs; (statisticians' score-Pearson's $r=0.97$, $p<0.01$; entomologists score -Pearson's $r=0.89$, $p<0.01$). Reliability between scores for the statement/statement pairs was significant at the 5% level (statisticians score-Pearsons $r=0.81$, $p<0.05$; entomologists score-Pearsons $r=0.76$, $p<0.05$) (Table 4.5).

Table 4.5: The reliability between the two persons scoring for question/answer, statement/statement and overall adjacency pairs expressed as Pearsons r.

Adjacency pair	Pearson's r	Level of significance
Q/A - Statistician	0.97	p<1%
Q/A - Entomologist	0.89	p<1%
S/S - Statistician	0.81	p<5%
S/S - Entomologist	0.76	p<5%
all pairs	0.86	p<1%

Table 4.6: Analysis of control in statement/statement, question/question and overall adjacency pairs.

Type of statement	Mean % stat	Mean % ento	Level of significance	Wilcoxon's T
Q/A	90	10	p<1%	34
S/S	79	21	p<1%	36
overall	82	18	p<1%	34

Table 4.7: Analysis of control for different statisticians (as percentage of initiated adjacency pairs).

	STAT 1		STAT 2		STAT 3		STAT4	
Client	m	m	m	f	m	f	m	f
Q/A	78	70	65	80	66	70	95	100
S/S	81	84	81	100	89	83	98	96
Overall	75	74	75	86	75	83	95	94

m=male f=female

The hypothesis that statisticians controlled the conversations was then tested. Statisticians controlled 82% of all utterance pairs (Wilcoxon's $t = 33$, $p < 0.01$). This overall control exercised by the statistician was also reflected in the control over question/answer pairs and statement/ statement pairs. Statisticians controlled 90% of all question/answer pairs (Wilcoxon's $t = 34$, $p < 0.01$) and 79% of all statement/statement pairs (Wilcoxon's $t = 36$, $p < 0.01$) (Table 4.6). Hunter (1981) discussed the roles a statistician can play: helper, leader and colleague. He defined the helper role as one in which the statistician asks few questions and tries to get the required job done quickly. In the leader role the statistician plays the active part and the client is passive. Both these roles are characterized by one-way communication, while the statistician as a colleague is involved in two-way communication.

The observed behaviour of the statistician in this empirical study seemed to fit the leader role. Statisticians commenting on statistical consulting (Zahn and Isenberg 1983, Gottinger 1988) concentrate on their role as colleague, and criticise the helper role (Hand 1988) as unacceptable. Dirlich et al. (1987) considered, maybe somewhat unrealistically, statistical consulting as centered around a dialogue between the consultant and the client, with both seeking to combine their differing expertise. This type of relationship is seen by statisticians as the most appropriate between consultant and client. The interactions observed in this empirical study did not coincide with this ideal.

The mean percentage of question/answer pairs versus statement/statement pairs was similar, with 47% of all utterance pairs being of the question/answer type and 41% of all utterance pairs being of the statement/statement type. The remaining 11% of utterances did not fit into either category. The interaction contained a mix of utterance pairs, as information has to be obtained from the entomologist and advice was given by the statistician.

(b) Qualitative comments.

Although the small sample size precludes further analysis of the interactions, some qualitative observation of trends can be made. Table 4.7 gives a breakdown of the percentage control the different statisticians had in each conversation. As before, data are presented for statement/ statement, question/answer and overall adjacency pairs.

Percentage control in all three types of categories differs between one statistician and all the others. Statistician number 4 had about 20% greater control than the other three. This may be an indication that the personal style of the statistician has some influence on the amount of control he or she wants to exert. There was no indication in this empirical study that the male statistician initiated Q/A or S/S pairs more frequently with female entomologists than with males entomologists, i.e. that they tended to control the conversation more when women were clients. Because similar analyses in other contexts (e.g. Maltz and Borker 1982) suggest that the sex of the participant can affect perception of control in social interactions, more investigation of this point may be warranted. Although difficult to assess in a sample of four, the influence of personal style could prove to be a significant factor in larger studies.

4.6 Conclusions

This empirical study used a method adapted from Coombs and Alty (1980). However, it differs from their work in several important aspects. Coombs and Alty (1980) recorded 'real time' interactions between computer consultants and computer users. Because these data were not available, the methodology was adapted to simulate consultations between entomologists and statisticians. The problems discussed in each interaction were very similar, whereas Coombs and Alty (1980) recorded various naturally-occurring problems. Initially the author attempted to follow Coombs and Alty's (1980) procedure closely. When problems in obtaining the participants' perceptions of the interaction occurred, this part of the methodology was discarded. Nevertheless this empirical study was successfully completed and analyzed. Mathiot (1978) claimed that participant's perception is crucial to the analysis of face-to-face interactions. However, her method was developed for real-life situations

.

Advisory interactions between statisticians and entomologists in the field of insect sampling plan design are a definable category of face-to-face encounters. The interaction can be stereotypically described as:

1. Information collection, consisting of:
    a. A problem statement
    b. Collecting information on the insect, the orchard, resourcses available, precision required, sampling methods, history and other topics.
2. Advice-giving, consisting of:
    a. General statistical issues
    b. Actual sampling plan or part of it
    c. Data analysis
3. Closing

Looping between information-collecting and advice-giving is common. Another typical aspect of the interaction is the long monologues by the statistician during the advice-giving episode. Control of the information flow resides largely with the statistician (overall and in any of the episodes). There is some indication of difference in personal style of the statistician in terms of amount of control exerted.

The role of the statistician as a leader (Hunter 1981) is an appropriate description of her or his function in the investigated interaction. The observed behaviour does not coincide with the type of behaviour that statisticians themselves see as most appropriate in statistical consultations. However, there have long been complaints by clients about the unsatisfactory nature of the relationship between statisticians and clients. These research results point to one possible cause for this dissatisfaction: an inappropriate amount of control of the conversation resides with the statistician.

This model of the interaction provides some clear guidelines for a computer implementation. It provides insight into the type of information to seek, the minimum amount of information necessary to come to a solution, and how information is elicited. Further research needs to concentrate in more detail on how information is elicited and the structure and sequence of questions and statements, as this information might influence the design of the user interface. Unfortunately, the situation observed did not conform to the 'ideal' interaction. As a cooperative undertaking it falls critically short; use of the results as a model for a computer implementation is an open question.

Cook and Salvendy (1989) reported on an exploratory study of the effect of different computer dialogue personalities on user satisfaction and performance. They found that users perceived computer dialogue personalities in the same manner as they characterize human personality, but that these personalities did not influence user satisfaction or performance. Further work in the area is clearly necessary, but the indications are that modelling 'ideal' human communicative behaviour will add little to a system's success or failure.

How to define and model an 'ideal' consultative interaction remains a further unanswered question. A more cooperative interaction should, however, contain flexibility in terms of language and thinking that could not be implemented at present. Future research must address these questions.

Chapter 5

ISPA - an expert system prototype for insect sampling plan design in the apple orchard environment

5.1 Introduction

Expert systems are potentially useful in many areas of entomology and have been developed for insect identification (e.g., Stone et al. 1986), pest management (Saunders et al. 1987) and to integrate simulation models (Stone et al. 1986).

Expert systems technology has also been applied to implement a number of statistical expert systems. These systems fall into two main categories: systems that help the user select an appropriate statistical tool (e.g., Xsample - an expert system advising on the univariate two-sample location problem, Gottinger 1988) and systems that guide the user in the application of the tool once it has been chosen (e.g., REX - an expert system for regression analysis, Prebigon et al. 1984). Systems that assist the user in the design of statistical experiments have not been widely reported.

An expert system in the insect sampling plan design domain needs to contain statistical and entomological knowledge. The commonly-held belief by entomologists about insect sampling plan design is that no universal sampling method exists (i.e., one algorithm that fits all possible sampling problems), but that statistical principles will provide guidance (Southwood 1976). However, Kogan and Turnipseed (1980) indicate the importance of a detailed description of all aspects of a crop/habitat for any insect sampling program. It may be possible to develop a more generalized approach to sampling design and at least identify the major constraints that affect sampling in a particular environment.

Most expert systems model a single consultation between expert and user. Insect sampling plan design requires repeated contact between statistician and entomologist, and any proposed expert system must take this into account. Advice from a statistician is usually sought on the design of a preliminary sampling plan, the analysis of any data collected and the design and analysis of a main sampling plan. The purpose of the preliminary sampling plan is to collect information on the insect's distribution and the optimal sample size. This information is incorporated in the main sample plan. The main sample plan is designed to collect the data in such a form that it will provide answers to the research questions. The following describes an expert system prototype that models multiple contacts between statistician and entomologist.

Just modelling the expert's problem-solving behaviour is not sufficient. If the expert also plays a consultative role, this role also needs to be implemented. The interaction between entomologist and statistician can be described as a three-part model: information-collecting, advice-giving and closing. Control of the interaction rests with the statistician (see Chapter 4). The prototype described here follows the model established in the previous chapter. While the observed interaction falls short of what statisticians consider 'ideal', the structure of an 'ideal' interaction is unclear and unknown. Furthermore, it is not known whether user satisfaction would significantly increase if a computer implementation of an 'ideal' interaction was implemented. Preliminary research (Cook and Salvendy 1989) indicated that different computer personalities have little effect on user satisfaction.

The expert system models insect sampling plan design as a choice between alternative plans. The choice between alternative preliminary sampling plans is chiefly constrained by an insect's particular environment. The insect's distribution and the researcher's resources (e.g., money, time) also have a major influence in the design of the main sample plan. The environment under investigation was the New Zealand apple orchard.

5.2. Description of a prototype expert system for insect sampling plan design in the New Zealand apple orchard environment

5.2.1 Overview

Expert systems development in statistics has concentrated on providing systems that provide statistical advice independent of the subject area to which it is applied. The difficulty with this approach is that systems of this kind must phrase the problems they can deal with in generalized statistical terms. The researcher wishing to apply statistics as a tool in her/his particular subject area may well not be familiar with these terms and/or prefer to discuss the statistical problem in terms of the particular subject area. If a statistical expert system is not intended to be used by statisticians themselves, then statistical knowledge as well as knowledge of the subject area to which it is applied must be included.

The prototype incorporates statistical as well as entomological knowledge. The problems that it can solve are purposefully narrow. The purpose of this work was to demonstrate that the approach, and the the ideas behind it, worked and that the conceptual framework is sufficient to solve the problem. For this purpose the depth rather than the breadth of the sampling design problem had to be explored.

5.2.2 The insect sampling plan domain.

The insect sampling plan domain has two dimensions. The first dimension describes the iterative interaction between statistician and entomologist during the course of a research project (Figure 5.1). Three interactions between the entomologist and the statistician commonly occur (see section 5.2.3b):

- Design of the preliminary sample plan.
- Analysis of the data from the preliminary and design the main sampling plan.
- Analysis of the main sampling plan.

The second dimension of the problem refers to the structure of each of these steps. To design an insect sampling plan, whether a preliminary or a main plan, the following questions must be answered:

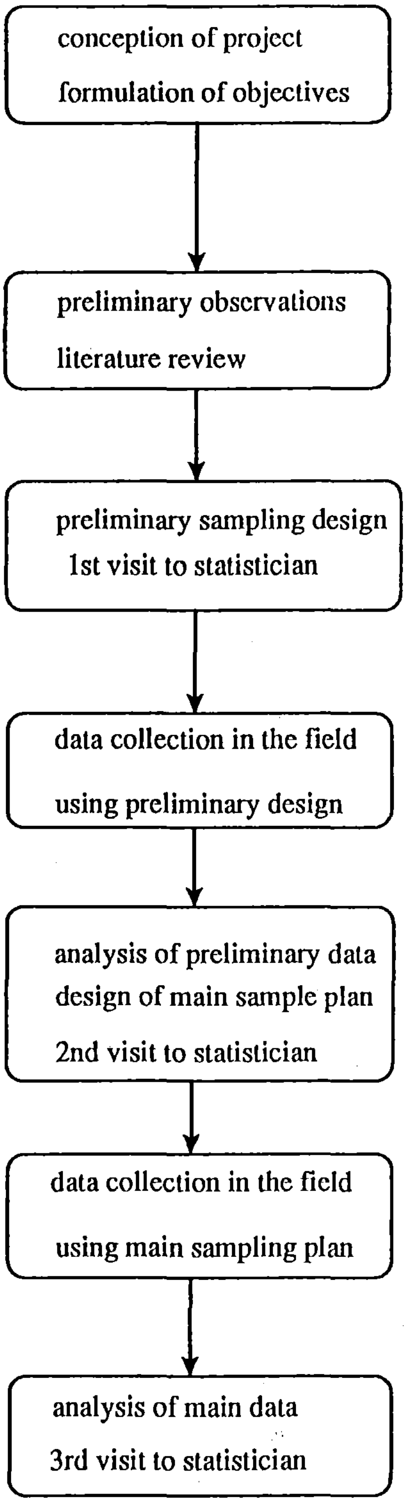
1.The spatial distribution pattern of the insect.
2.Sample size estimation or magnitude of change to be recorded.
3.Selection of the sample universe.
4.Definition of the sampling unit.
5.Distribution of the sample unit in time and space.
6.Major sources of variance.
7.Cost efficiency of sampling method.
8.Biology of the insect and knowledge about its habitat (Morris 1960).

The preliminary sample emphasizes answers to spatial distribution and optimal sample size. The main sampling plan incorporates information gathered in the preliminary sample (by analysing the data gathered) and produces a plan that balances sample size estimation required, research objectives and resources available.

In practice a sampling plan for insects in the orchard environment (i.e., living on trees) specifies:

1.How many trees to sample.
2.How to locate these trees.
3.How to subdivide the trees that are sampled.
4.How many samples to take from each subdivision.
5.How to locate each sample.
6.What constitutes the sampling unit.

Figure 5.1: Stages in entomological field research.



5.2.3 Systems overview.

(a) Languages used.

The prototype was written in Turbo Prolog 2.0 (Turbo Prolog 2.0 Reference Guide 1988) and Turbo Pascal 5.0 (Turbo Pascal Reference Guide 1988). Earlier versions were written in CLIPS (see section 3.3.4). The present system has 195 rules (excluding Prolog tools) and about 4000 lines of Pascal code. It uses Prolog's built in backward-chaining inferencing mechanism. Turbo Pascal provides the graphical representation of the orchard layout. The inferencing part of the system was initially written in LEVEL5 (PC Version Level 5 Users Manual 1987), an expert system shell. It was rewritten in Turbo Prolog, because the shell had too many programming and interface limitations.

Turbo Prolog is a declarative language based on first-order logic. It incorporates many concepts not implemented in other languages, including pattern matching and backtracking (Filipic 1988).

(b) Overall structure

A task analysis of entomological field research by the author showed that this kind of research consists of a number of distinct stages (Figure 5.1). Contact with a statistician is made during the preliminary design, during the analysis of the preliminary data and the design of the main sample plan, and during the analysis of the main sample data.

The prototype is an interactive tool, intended to be used by entomologists. Its requirements are:

1. To give advice on the preliminary sampling plan.
2. To support entry of the data collected in the preliminary sampling.
3. To analyse the data from the preliminary sampling plan.
4. To advise on the main sampling plan design.
5. To analyse the data collected in the main sample.

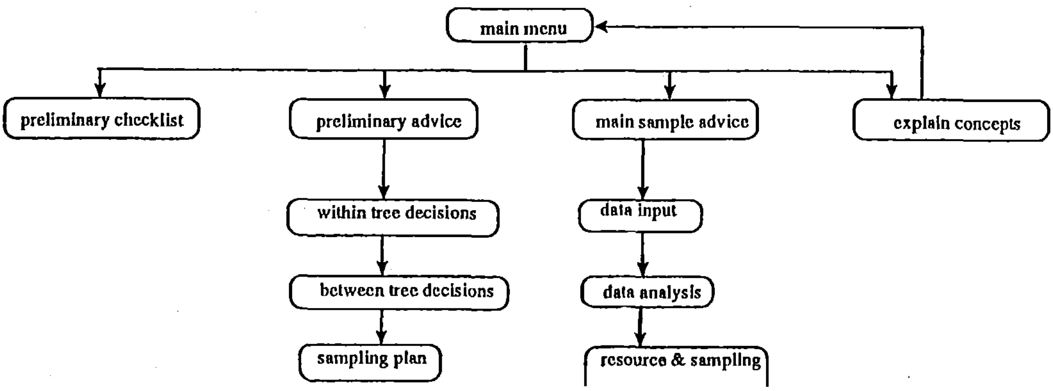
Step five in the above process was not implemented. In principle this step is similar to step three, but presents additional problems in terms of what statistical technique to select for the analysis of the data. This was beyond the scope of the present prototype.

Steps one to four were implemented as separate modules. Modularity is critical to the success of a prototyping approach, because it must be possible to continue reorganizing the knowledge base as the knowledge engineer's understanding of the problem evolves (Mugridge and Hoskin 1986).

Figure 5.2 shows a hierarchical representation of the overall system. A main menu controls the branching into either preliminary design, main sampling design, explanation of general terms or the printing of the preliminary checklist. Inclusion of explanation of some general terms was suggested by the main expert when an early version of the present prototype was shown to him for evaluation. The preliminary checklist is a user aid which ensures that the user is aware of the information needed for successful insect sampling plan design. It was also used to present the test cases to the statistician in a standardized, unbiased form (Chapter 3 - knowledge acquisition by simulating test cases).

Appendix 11 contains a list of all the files necessary for the system, with information on the language each file is written in and the functions it performs. The executable version and the file listings are available on a floppy disk (double sided, high density, 5 3/4 inch). The prototype runs on an IBM AT/XT-compatible, with a minimum of 640K, and a Hercules mono or EGA monoscreen.

Figure 5.2: Modules and major within module decisions of the prototype for insect sampling plan design in the New Zealand apple orchard environment.



(c) Knowledge representation and knowledge base structure.

Knowledge and problem solving strategies of the expert were captured in decision trees (Chapter 3). The decision trees were then converted into rules.

The insect sampling plan design problem could be subdivided into between-tree (how many and which trees to sample) and within-tree (how to subdivide the tree and how many samples to take) decisions. These two sets of decisions were treated as independent of each other. The statistical analysis module consists of submodules that determine the possible distribution of the insect, whether there were outliers, and if any of the within- and between-tree subdivisions were of importance.

Rather than dealing with one large problem, the system solves a number of small, independent problems by applying the appropriate heuristics. These problem-solving modules are linked in a hierarchical structure.

Uncertainty was not included in this system, because uncertainty was not apparent during knowledge acquisition.

(d) The user interface

Overview

The issues surrounding the design of the user interface include consideration of how to design particular screens, use of graphics, and adapting to the needs of different types of users (Galitz 1989). The interface for this expert system was designed for the entomologist user who has some basic knowledge of statistics.

Dialogue structure

The author aimed to make the dialogue sensible to the user, both in language used and order in which the consultation occurs (see next section). The overall dialogue structure is rigid and does not allow for any short-cuts (i.e., skipping menus).

Whenever possible, choices between alternatives are presented in a menu, from which the user is asked to choose the appropriate answer. Menus are preceded by short explanations pertaining to the choices available. Feedback to the user on information collected so far and overall intentions behind a group of questions are also provided. For example, when all the necessary information for within- tree decisions are collected, the user is provided with a summary of this information.

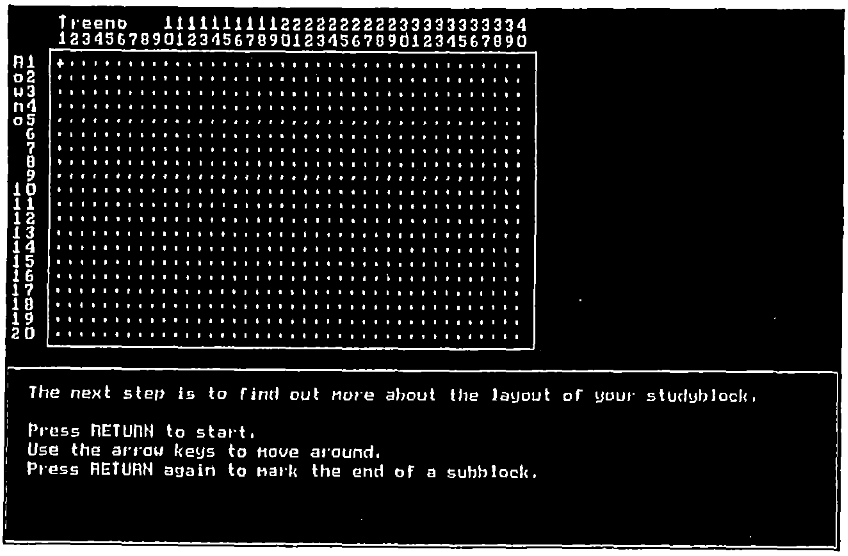
Graphical representation of the studyblock layout

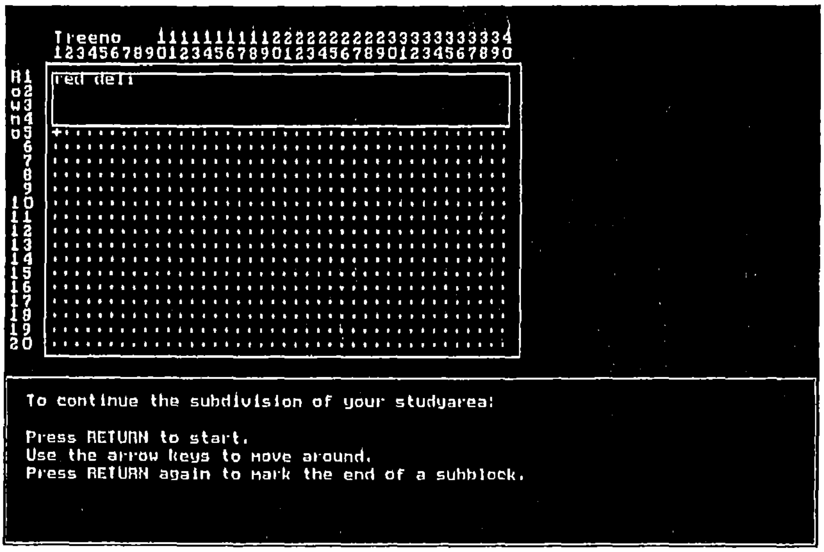
Of major interest to the statistician is the physical layout of the study block (a study block is the area of orchard that the entomologist wishes to study). Commonly, the entomologist presents this layout to the statistician in form of a schematic drawing. In the first prototype, communication about the layout was achieved through a dialogue of questions and answers. It is difficult, however, to elicit information in this manner. A graphics interface that facilitates communication via a schematic drawing was implemented for the second prototype (Figure 5.3 for example screens). This interface models how the statistician and the entomologist communicate about the layout more directly. It is described in more detail in section 5.4.2

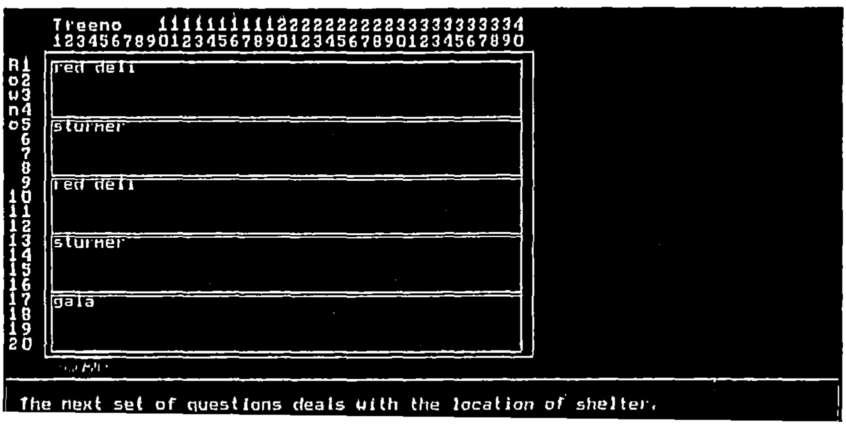
To ensure that the schematic drawing and the vocabulary used reflected the entomologist's perception, a pilot survey of six entomologists was conducted. Its purpose was to elicit the type of diagrammatic representation used by entomologists and the terms used to describe a study block. The entomologists were presented with two questions and a covering letter. Question one asked them to describe an orchard in any way they felt comfortable with, and question two asked them to describe in detail all important features of the diagrammatic representation of the orchard supplied with the question (Appendix 12).

Results of this survey indicated that 25 different terms were used to describe an orchard. Of these the following terms were used more than three times: cultivar, shelter, row orientation, number of blocks. Three out of the six participants used diagrams to describe the orchard of their choice, and the other three used words only. These diagrams were similar to the diagram they were asked to label in the second section of the survey.

<u>Figure 5.3:</u> Samples screens illustrating how information on the orchard layout is requested.







5.2.4 Description of modules

(a) Overall control module

This module controls the selection of the other modules of the system. It presents the user with a title window, a list of constraints of the system and a main menu. This main menu offers a choice between selecting advice on the preliminary design, advice on the main design, explanation of concepts or a print-out of the preliminary checklist.

(b) The preliminary design module

Overview

Figure 5.4 shows the program flow for the preliminary module. The user is given a choice whether she/he wants to start the preliminary design or get some definition of terms. She/he is reminded that information requested during the consultation is based on the initial checklist and a choice of printing is provided. A number of constraints are implemented to ensure that the requested advice fits into the constraints of the problem, i.e., the study block must be less than 10 ha, only one study block is permitted and the objective of the sampling must be to ascertain relative population levels of one species. In later versions these checks can be replaced by modules that deal with these particular areas. Within-tree and between-tree decisions are dealt with separately (see Chapter 3, Figure 3.8, p.58 and 3.7, p.55 for the decision tree). Finally, the advice is displayed to the user, who then can decide whether to print it and/or save it for later use.

Within-tree decision submodule

This module is an implementation of the within-tree decision rules (see Chapter 3, Figure 3.8, p.58). The user provides the necessary information on the insect lifestage and the microhabitat by selecting the appropriate answers from multi-choice menus (Figure 5.5 for example screens). Before moving to the next submodule, the user is given a summary of the information collected so far (Figure 5.6 for example screen).

Figure 5.4: Program flow of the preliminary design module, as program decisions and information to be collected from the user.

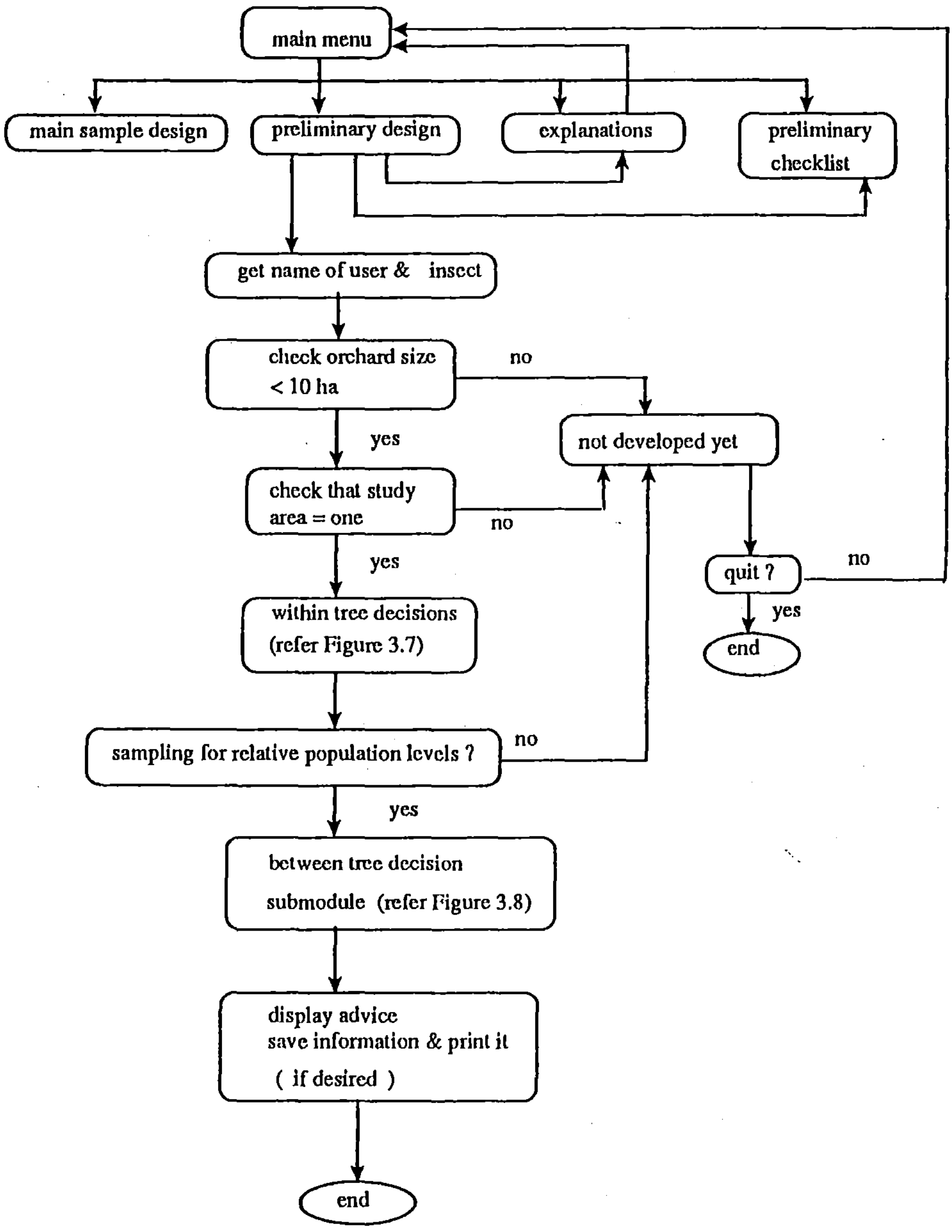


Figure 5.5 Sample screen from the within-tree submodule, showing multi-choice menus to collect information on insect micro-habitats.

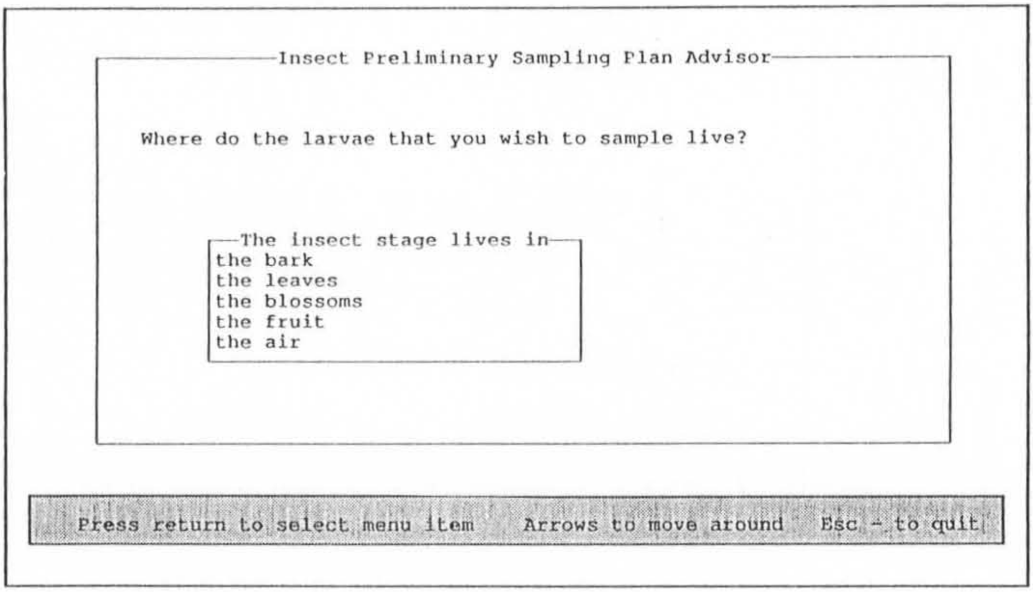
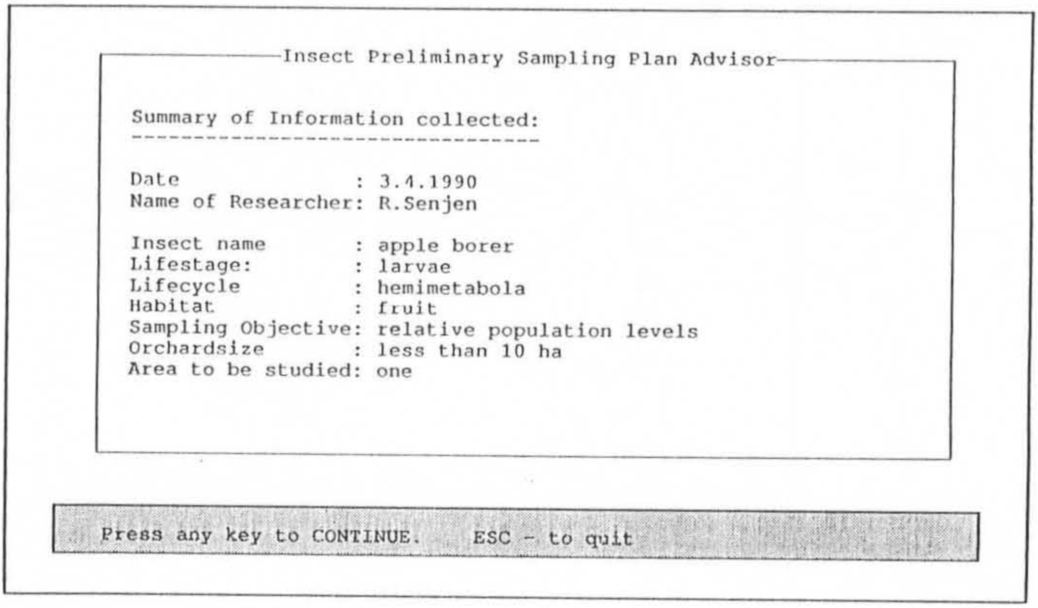


Figure 5.6 Before moving to the next submodule the user is given a summary of the information collected so far.



Between-tree decision submodule

The between-tree decision module is written in Turbo Pascal 5.0, because this language interfaced reasonably well with Level5 and has good graphics capabilities. Level5, an expert systems shell, has limited graphics capabilities and was used for the first implementation of this prototype.

Figure 5.7 shows the program flow. The user is asked for the number of rows in the study block and the number of trees per row. The system then displays a schematic outline of the orchard and the user is asked to delineate cultivar subblocks and to name them (Figure 5.3 for sample screens) Error trapping has been implemented, i.e., the user cannot go beyond the boundaries of the study block and only the arrow keys and the return key are available for use during the delineation of a cultivar subblock. The system also asks whether the study block is surrounded by shelter and on which sides the shelter is located. When the program has made the decisions on how many trees and which particular trees to sample, control is returned to the preliminary module.

Figure 3.7 (see Chapter 3, p.55)) shows the decisions that must be made to ascertain how many trees need to be sampled. Once this is done, this section of the program randomly selects the actual trees to be sampled in each cultivar subblock. In a consultation between a statistician and an entomologist, the statistician would normally indicate only the principles to be followed when selecting the actual trees, i.e., he/she would advise the entomologist which trees to exclude from the pool of possible trees to sample (see Chapter 3, Figure 3.12 p.67, for the decisions involved).

Advice submodule

When all decisions are made, the user is presented with a summary of the information collected and the advice given (Figure 5.8 for sample screens). Both can be printed if desired. The advice gives details on how many trees to sample per cultivar and how to subdivide these trees. This module also includes a list of actual trees to sample, i.e., those that have been chosen at random by the program. A diagram showing the study block layout with the actual trees to sample marked is also displayed.

Figure 5.7 Program flow for the between-tree decision module (preliminary design).

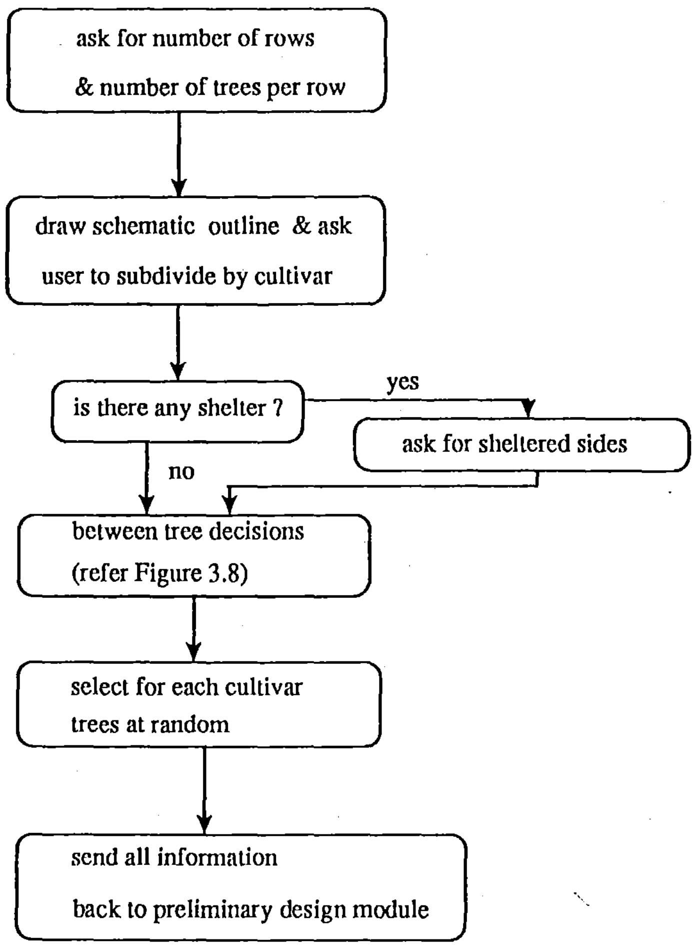


Figure 5.8: Example of advice screens.

```
Insect Preliminary Sampling Plan Advisor

RECOMMENDATIONS based on your answers are:

1.  Number of trees to be sampled per cultivar:
-----------------------------------------------

                                       No of trees
Cultivar name       No of Subblocks    sampled/subblock
-------------       ---------------    ----------------

red deli                  2                2
braeburn                  2                2

     Press any key to CONTINUE.     ESC - to quit
```

```
Insect Preliminary Sampling Plan Advisor

2. Individual tree strata subdivision:
--------------------------------------
Suggested subdivision: 8 strata.

Initially  each tree could be subdivided into two vertical
halves (height) and 4 quarters e.g. east, west, north, south.

3. Number of sample units to take per strata:
---------------------------------------------

Suggested number of sample:10 fruit

     Press any key to CONTINUE.     ESC - to quit
```

```
Insect Preliminary Sampling Plan Advisor

4. Actual trees to be sampled:
------------------------------
Please note that rownumber refers to the x-axis, while
treenumber refers to the y-axis.

      Tree Number  Row Number
      -----------  ----------
          24           3
          20           2
          16          10
           8          11
          15           6
          13           5
          21          13
          17          14

     Press any key to CONTINUE.     ESC - to quit
```

(c) The main design module

Overview

The main design module consists of three parts: data input, data analysis and advice on the main sampling plan. It assumes that the user has previously used the system to obtain a preliminary sampling plan, and has used this plan to collect data in the field (i.e., advice obtained for the preliminary design is saved in a file).

Data input

The data input module asks the user for the name of the file that contains the preliminary design information. The user is then presented with a data input sheet that resembles a spreadsheet. Within-tree subdivisions are indicated along the horizontal. The vertical contains a row for each tree that was sampled. The data are typed in via a data input window (Figure 5.9) All headings and the current input cell are highlighted.

The spreadsheet format was chosen as it most resembles the data sheet the entomologist is likely to use in the field.

Data analysis

The data analysis module performs three functions (Figure 5.10). First, it computes the number of zeros in the data and transforms the data if necessary (see Chapter 3, Figure 3.11, p.63). The data are transformed (with a square-root transformation), if the distribution that fits the data best is a negative binomial; otherwise the assumptions pertaining to an analysis of variance would be violated. Second, it performs an analysis of variance on the data, to ascertain which, if any, of the factors (i.e., height, aspect or cultivar) are significant. Finally, it tests whether the data contains any unusually high values (outliers), using the boxplot procedure (Velleman and Hoaglin 1981). A boxplot summarizes graphically the main features of a data set, namely the median, the extend of each quartile or hinge and the position of the inner (lower or upper hinge-1.5*hinge spread) and outer fence (lower or upper hinge-3*hinge spread). Any value beyond the outer fence is considered an outlier.

Figure 5.9: Data input window, as seen by user.

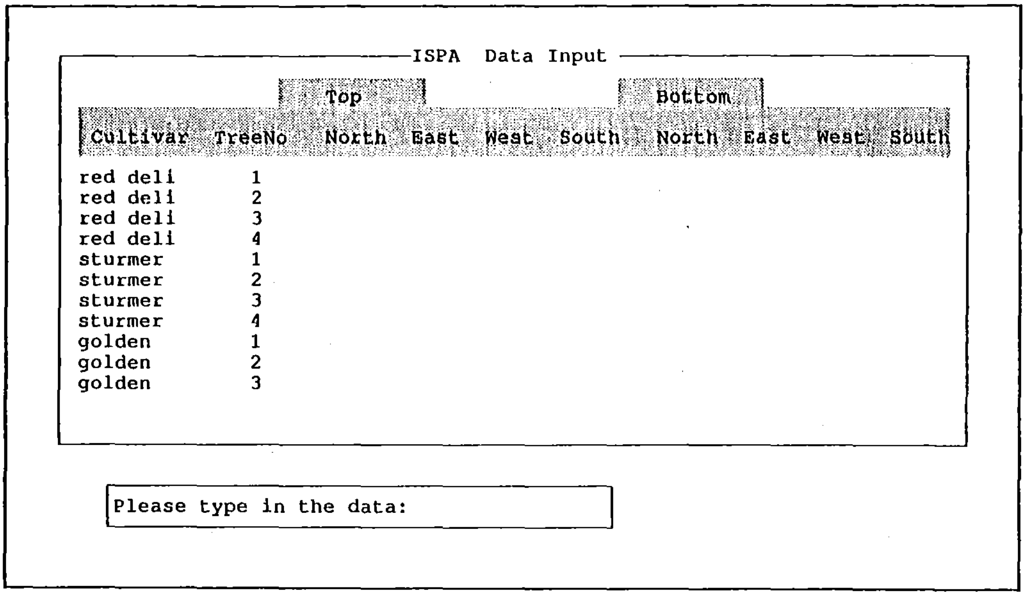
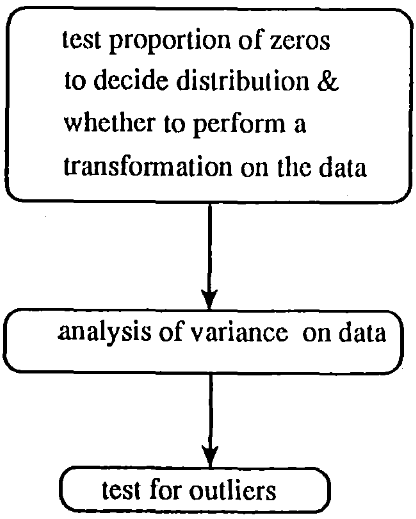


Figure 5.10: Program flow for data analysis module.



Main sampling plan design

This submodule implements the decision process for the main sampling plan design (see Chapter 3, Figure 3.10, p.62) by using the results computed by the data analysis submodule and by obtaining information from the user. The system also informs the user of the results of the data analysis and their possible implications (Figure 5.11 for sample screens from the main sample).

For instance, when the user enters a set of preliminary data, it is checked to see if an outlier occurs in it and whether this has previously occurred. This information is taken into account when advising on the data set. If the outlier has occurred for the first time, the user is advised to repeat the preliminary data collection to ascertain whether unusually high values are common to this insect sampling problem. If the outlier recurs in the second data set, the user is referred to a statistician.

If no outliers are indicated, the system will advise the user on the frequency distribution that best fits the data. In some cases, the system will ask for further information - e.g, if a negative binomial distribution is indicated, the user is asked whether this might be due to the fact that insect numbers are still increasing.

The user is also advised whether any of the strata (within- tree subdivisions) are significantly different (in a statistical sense) from the other strata or whether the strata subdivision can be reduced.

The decision about how many trees to sample per cultivar follows the between-tree decision rules for the main sample plan design (see Chapter 3, Figure 3.13, p.67). This number is compared with the number calculated by a formula incorporating the precision required by the user (the higher numbers are chosen). The system also checks whether the user has the resources necessary to sample the calculated number of samples. If necessary, the sample number is adjusted downward (which results in a loss of precision). Finally, the user is presented with a summary of the advice, specifying the number of trees to sample and how to subdivide these trees (Figure 5.12 for sample screens). Actual trees are not pre-selected for the user (as in the preliminary sampling), but a reminder is provided about the general rules to follow when selecting trees randomly from a cultivar subblock.

Figure 5.11: Sample screens from the main sample plan design.

```
Insect SamplingPlan Advisor

The number of zeros in your preliminary sample is in
the range of 1/6th to 1/4.  Additionally the range of
observed values lies between zero and 8

The reason for the high number of zeros could be that
it is the start of the season for the insect in question,
       and numbers might increase later.

The high number of zeros observed is due to

  That it is the beginning of the season.
  Not, due to the beginning of the season.

Press any key to CONTINUE.    ESC - to quit
```

```
Insect SamplingPlan Advisor

The data from the preliminary showed significant
differences between the cultivars.

      If this statistical observation has any biological
relevance can not be determined at the preliminary sampling
stage.

Press any key to CONTINUE.    ESC - to quit
```

```
Insect SamplingPlan Advisor

In order to calculate the number of sample to take in the main
sample, we need to know the true difference as a percentage of
the mean that you would like to be able to detect.

This number depends largely on your sampling objective.  A low
value e.g. 10 is recommended when you are interested in
monitoring populations for example.

The level of discrimination is:15

Press any key to CONTINUE.    ESC - to quit
```

Figure 5.12: Sample screen showing the advice the user is given for the main sample plan.

```
Insect SamplingPlan Advisor
Summary Report

You have found the workload acceptable.

The number of samples to take in the main sample is: 40

This can be split up as follows:
Trees sampled: 20
Aspect divided into: 2 strata.
Height divided into: 1 strata

Number of samples per strata remains the same as for
the preliminary.

Press any key to CONTINUE.    ESC - to quit
```

```
Insect SamplingPlan Advisor

When selecting trees at random from a cultivar subblock
a few simple rules need to be followed:

1. If the cultivar has < 3 rows, discard the two short
   edge rows
2. If the cultivar has > 4 rows discard all the edge rows
3. If the cultivar has 3 or 4 rows and it is on the outside
   of the studyblock, then discard the three rows that are on
   the outside, otherwise discard the two short edge rows.

Press any key to CONTINUE.    ESC - to quit
```

(d) The preliminary checklist (a user aid).

Interviews with the main expert revealed that clients are perceived too often as ill-prepared with regards to information on the insect and its habitat and research objectives, especially on their first visit. This perception led to the idea of an initial checklist. An initial checklist is a list of questions that provides the client/user with an idea of the sorts of information the statistician/ expert system requires to advise on the preliminary sampling design.

Lists of general questions have been compiled by a number of statisticians (i.e., Cox 1958). Jeffers (1978) produced a more detailed, but still very general, checklist of 71 questions. The list compiled here is much more specific, and is only applicable to insect sampling plan design in the orchard environment (see Chapter 3, Figure 3.6, p.51).

The initial checklist reflects what the statistician views as an ideal starting point for the first consultation. It forms the basis for the statistician's expert judgments about appropriate sampling of insects in the orchard environment. The checklist also serves as a recording sheet that enables the statistician to keep track of information received and initial advice given. Initial informal responses by other statisticians and by entomologists to the checklist have been positive. To further refine the checklist and to represent more than one statistician's perceptions, it would be necessary to conduct a formal survey amongst statisticians and clients (see Capter 3, Section 3.4.4 for an explanation on how the checklist was developed).

5.3 Discussion

The objective of the present study was to implement a prototype expert system for insect sampling plan design in particular environments. This has been achieved. The present prototype can be described as a demonstration (Guida and Tasso 1989) or research prototype (Waterman 1986). It demonstrates that in principal an expert system in this field is possible.

The prototype advises on the preliminary design, carries out analysis of the data collected in the preliminary sample and advises on the design of the main sampling plan. It incorporates statistical as well as entomological knowledge, and resembles in design other rule-based entomological expert systems. The prototype establishes the principal decisions that are made in insect sampling plan design for a particular environment.

Various implementations of the present prototype were shown to the expert, and the resulting discussions added to the continual refinement of the prototype. The prototype advises on insect sampling plan design in the New Zealand apple orchard environment. It covers the problem area in the sense that, when the present prototype was shown to the expert, he agreed that it modeled his advice adequately.

Is an expert system for insect sampling plan design practical ?

The question, that remains to be answered, is whether an expert system in the field of insect sampling plan design for particular environments is not only possible, but practical.

At present the prototype is limited in a number of areas (excluded are insect lifestages living in the soil, situations where treatments are applied, situations where more then one study area is involved or were absolute population levels are required, and more complex orchard systems), but the prototype does solve a narrow portion of the overall problem (insect sampling plan design) in depth.

The system could easily be extended to cover soil insects and other orchard types (e.g., citrus, pear, kiwifruit), because these extensions do not introduce new decision-making principles. In any case, absolute population levels are rarely estimated (Worner 1990). An inclusion of surveys of insect abundance over a large geographical area (e.g., all apple orchards in a particular area) would need access to electronic maps. This would not present a difficult problem.

Future work needs to concentrate on including situations where treatments are applied, and checking the validity of research objectives. Both are difficult problems.

Incorporating situations in which treatments are applied is primarily a knowledge acquisition problem. Within an orchard environment, treatments may be applied to parts of a tree (i.e., branches, subdivisions of the tree, individual trees) or parts of the orchards (i.e., rows, individual trees, study blocks). Additionally different types of treatments may be applied (i.e., chemical sprays, biological control agents, mechanical control agents). Combining all the possibilities will result in a very large number of test cases and it is at present not clear how the number can be reduced to a manageable level.

Our expert commented that sometimes entomologists ask for advice on an insect sampling plan without being totally clear what the objectives of their research are or their objectives are not attainable within the constraints of resources and environmental factors. In these cases the statistician is called upon to help clarify or modify the entomologist's research objectives. While the present prototype could be extended to accommodate different research objectives, clarifying or modifying research objectives would present knowledge acquisition and implementation problems. For instance, what are the differences between clarifying and modifying research objectives and how could they be elicited. It seems unlikely that all the possible cases of modification and clarification could be anticipated (as is the case with the present prototype), and consequently new reasoning strategies would need to be implemented.

In summary implementation of an expert system for insect sampling plan design is practical, as long as the system is restricted to providing only a sampling plan and analysis of data. The present prototype could be relatively easy extended to cover other orchards, larger geographical areas and insects living in continuous sampling units (e.g., soil).

5.4 Summary

An expert system prototype for insect sampling plan design in the New Zealand apple orchard environment was developed. This prototype shows that an expert system in this domain is feasible. The prototype advises on the preliminary design, carries out the analysis of data collected in the preliminary sample and advises on the design of the main sampling plan.

The present system does not cover a number of areas that need to be addressed in future research, e.g., experiments where treatments are applied, and designing insect surveys for large geographical areas.

This prototype differs from other statistical expert systems in that it incorporates not only statistical knowledge but also knowledge about the subject area in which the statistical knowledge is to be applied. This approach seems prudent, as statistics are often used as a tool and knowledge about the subject matter to which it is to be applied is important in order to apply the tool correctly.

The systems design resembles other rule-based entomological expert systems reported in the literature. Its reasoning strategy follows those used in most diagnostic/ classificatory expert systems. Problem solving becomes a choice between a set of pre-determined alternatives.

Chapter 6

General Discussion

6.1 Introduction

This study on the implementation of an expert system prototype for insect sampling plan design provides the opportunity to develop new techniques for systematically eliciting knowledge from the expert, and to investigate the advisor-client relationship which is part of the insect sampling plan design process. The study also provides a general plan for sampling in a particular environment (New Zealand apple orchards).

In this chapter the problems with some current expert systems techniques and the elements of effective advice and advice-giving relationships are discussed. Furthermore, the contributions of the expert systems prototype developed in this study are discussed and the usefulness and implications of expert systems technology as a tool for better understanding a specific domain is argued.

6.2 Problems with expert systems development

One of the major approaches of expert systems development, and in fact a commonly used definition of an expert system, is that expert systems model human problem-solving in a particular field. This approach is problematic because it does not consider that intelligent problem-solving is an activity frequently done in the context of giving advice, rather than an autonomous task in itself. Consequently, systems that are designed use a human expert solving problems in isolation as a model. This is one of the reasons that many demonstration expert systems are often abandoned by their developers (Roth and Woods 1989).

Rather than specifying the possible range of problems within the domain and the factors that contribute to problem difficulty, these developers concentrate on building systems using knowledge from very specific, and often narrow, problem sets.

The reason for the inability of many expert systems to solve a sufficient large range of problems is an overreliance on an iterative refinement approach during the system's development (Roth and Woods 1989). This approach is often given as the standard approach for expert systems development (Hayes-Roth et al. 1983). Initially a small set of example cases are discussed with the expert, and the rules emerging from these discussions are used to implement a first prototype. Subsequent prototypes are developed by testing the performance of the prototype on new cases and slowly refining it.

Roth and Woods (1989) claimed that the iterative approach is inefficient for knowledge acquisition as well as knowledge-base development. Knowledge acquisition tends to concentrate on the straightforward cases, and an attempt to develop a formal description of the problem space is rarely made. Similarly, systems developers often omit to delineate the range of problems the system can handle. The result is that users are given little guidance as to when it is appropriate to use the system and when not. When the expert system is expanded to include new cases, a major restructuring of the knowledge base is frequently necessary (Bachant and McDermott 1984). Effective and efficient knowledge acquisition needs to rest on a theoretical framework. This would facilitate the delineation of what knowledge to elicit and provide a base for structuring the procedures of knowledge acquisition (Garg-Janardan and Salvendy 1987).

Knowledge acquisition by simulating test cases

Knowledge acquisition by simulating test cases - a technique developed in the context of this study - can be used to specify the possible range of problems within a given field and to identify the factors that contribute to problem difficulty. The possible range of problems is specified by defining the range of each constraint or characteristic thought to influence the choice of a decision. These can than be combined to yield test cases that can be presented to an expert. The expert's choice of sampling plan can be used to infer which constraints are crucial for a particular decision. The cases that the expert finds difficult can be examined to reveal the characteristics or constraints that have a major influence on problem difficulty. Occasionally the expert herself/himself may point out these constraint or characteristics.

Knowledge acquisition by simulating test cases makes knowledge acquisition more efficient and effective. It is not an ad hoc method, but relies on the theoretical basis of decision theory (Lancaster 1966, Tversky 1972) and the practical methodology of the experimental technique. It is suitable for domains where the solutions are diagnostic or classificatory. While Roth and Woods (1989) may be right in some of their criticism of the iterative approach, it remains a useful part of knowledge acquisition, as it allows feedback from the expert and users to be incorporated in the system quickly. Knowledge acquisition by simulating test cases alleviates some of the problems associated with the iterative approach.

6.3 Advice-giving systems

Elements of good advice-giving

Examination of human-human advisory interactions can provide developers of human-computer advisory systems with the characteristics of successful advisory interactions. Human-human advisory interactions have been investigated in a number of fields, e.g., face-to-face advice on use of computer systems (Coombs and Alty 1980), radio talk show advice on financial management (Pollack et al. 1982) and advice on the use of library information systems (Belkin et al. 1987). The results of these studies and other more general papers on the issue of advice-giving systems (e.g., Carroll and McKendree 1987, Roth and Woods 1989) indicate that good advice is more than recommending a solution :

- The advisor aids the client in problem formulation and plan generation.
- The advisor helps the user to ask the right questions and evaluate possible answers.
- The advisor does not always provide a complete solution. Sometimes a solution consists of listing strategies and plans, while at the same time eliminating actions judged unsuitable.
- The user/client monitors, probes, and contributes information to ensure the advisor's recommendations are based on an accurate representation of the user's/client's problems.
- Control of the interaction is shared.

Advice-giving styles

The above list implies a style of advice-giving that some authors have termed co-operative problem-solving (e.g., Kidd and Sharpe 1989, Worden et al. 1987). Kidd and Sharpe (1989), on the basis of empirical data, formulated task requirements for a computer implementation of such a system:

- An ability to answer a range of questions about the problem solving task.
- An ability to negotiate between itself and the user to ensure the problem formulation captures significant aspects of the user's problem.
- Generation of alternative solutions to cover questions that fail (e.g. 'Will X achieve Y ?', 'No, but W will') or succeed ('Yes, but so will W').
- Detection of user misconceptions, and an ability to describe relationships between alternative solutions and to provide justifications for solutions.

At present none of the available expert systems employ a co-operative style. The two most commonly-used styles are the socratic style and the learning-by-doing environments (Carroll and McKendree 1987). The socratic style refers to a style where the system asks questions and the user provides the answers. Control rests entirely with the system, relegating the user to a passive role of following instructions. In the learning-by-doing environments (e.g., SOPHIE - Burton and Brown 1982) each user move is compared with an expert move (generated by the system) and feedback is provided about it to the user. This type of strategy has been employed mainly for the development of educational games, where the number of possible moves is small.

The level of advice

A further issue in the development of advice-giving systems is the level or 'grain' of advice to be given. While highly specific advice is likely to be the most effective, it can be very difficult to implement because it relies heavily on context-specific information. This information may not be contained in the system, or it may be unobtainable from other sources. In contrast global advice is more robust, in the sense that it will be right at least on some level (Roth and Woods 1989). A problem or task itself may, to a large extent, determine the level of advice needed (at least for the more straightforward problems), but once a task or problem involves several goals the issue of the most effective level of advice has to be solved. Roth and Woods (1989) cited the case of a process control task, which on the surface required a highly specific solution (to optimize the goal of maintaining the control level within tight bounds around the target). However, other goals (e.g., the need to control a second process affecting control level) made it necessary for the machine advisor to generate a broad target band, rather than an 'optimal' target value as its recommendation.

People are not always the best models

The first step in any implementation of an advice-giving system must be the observation of the human-human advice-giving relationship. A model of this relationship can then be integrated with a model of the expert's problem-solving behaviour. In both cases the developer must not fall victim to the a priori assumption that how people do a particular task (e.g., problem solving, advice-giving) is the optimal way of performing it. Roth and Woods (1989) warned that the strategies used by even the best experts can be convoluted, suboptimal or developed in response to an impoverished support environment.

Roth and Woods (1989) cited the case of a boiler level control expert system they were asked to develop. During knowledge acquisition they found that information on boiler behaviour was not sufficient for any person or machine to perform the task well, and even the best operators used only indirect measures of boiler behaviour. In response to this problem, Roth and Woods (1989) developed new and more accurate sources of boiler information and used this information in turn to build a better assessment of boiler control levels. The computational mechanisms used were very different from the surface strategies used by the better boiler operators. Preliminary testing of the system showed improved performance of less skilled operators and an increased range of situations that could be handled overall.

Techniques used in the observation of human-human advice-giving

Numerous techniques have been developed to elicit the expert's problem-solving behaviour and represent it in a computer model. Relatively little research has been done on the human-human advice-giving relationship and few techniques are available for the purpose of modelling this relationship. A form of discourse analysis is usually used to ascertain the roles of the participants and to develop a model of the functions performed during advice-giving. Research has concentrated on naturally-occurring interactions (Coombs and Alty 1980, Pollack et al. 1982, Belkin et al. 1987), but these may not always be available.

The advice-giving relationship between statisticians and entomologists in insect sampling plan design

The present study of the advice-giving relationship between statisticians and entomologists is a first step towards an advice-giving expert system in this field.

The advice-giving relationship between statisticians and entomologists contains elements of 'good' as well as 'bad' advice-giving. Advice given by the statistician sometimes contains other possible solutions, solutions that should be discounted or discussions on related topics (i.e., general statistics, data analysis). A less positive aspect of the relationship is that the control of the interaction rests mostly with the statistician. The entomologist, rather than monitoring and contributing information to ensure that the statisticians recommendations are based on an accurate representation of the entomologist's problem, is mostly treated as a passive information provider.

This study serves to point out shortcomings in the statistician-entomologists advisory relationship that may be of interest to the statistical community at large.

The interaction can be characterized by a three-part model: information-collecting, advice-giving and closing. In 75% of the interactions, the statistician cycles between information-collecting and advice-giving. The function that this cycling serves is not clear. It could indicate that the statistician, like medical practitioners, uses a process of hypothesis generation and verification to solve problems (as suggested by Hand, 1984). More simply, it could have a memory and confidence building function or it may be an attempt by the statistician to show the client how the statistician reasons.

Whether a machine-advisor should follow a similar pattern, or whether this would be a case of copying a suboptimal human strategy, is a topic for future research. Comparing the two advice patterns and deciding which of the two is more 'successful' would, however, not be an easy task, because it would involve subjective judgment by users/clients, rather than comparison with objective standards.

A technique for recording and analyzing simulated advisory interactions

The technique used in this study for observing and analysing the advisory relationship of statisticians and entomologists is an adaptation of a technique used by Coombs and Alty (1980). The major differences between the two techniques are:

- Simulated rather than 'naturally' occurring interactions were used.
- The participants' perceptions of their interactions were not used.

Using simulated interactions is useful when 'naturally' occurring interactions are not readily available, and gives greater control of the experimental setting.

Mathiot's (1978) technique was developed to record and analyze 'naturally' occurring interactions. In these interactions the functions of the interaction and the roles of the participants are not strongly predetermined, and it is therefore useful to collect the participants' perceptions of these interactions. In a simulated interaction the participants are briefed on the functions of the interaction. Asking participant's for their perception of the interaction, was in hindsight, unreasonable and unnecessary.

The technique was used successfully to establish a model of the advisory interaction and to ascertain the control each participant had over the interaction. When the technique for simulated advisory interactions is used, the participant's perception of the interactions does not need to recorded.

6.4 ISPA - a prototype expert system for insect sampling plan

A prototype expert system for insect sampling plan design was developed. The prototype expert system includes entomological as well as statistical knowledge. Previous expert systems developed in statistics have only used statistical knowledge and their lack of acceptance by users (statisticians and clients) may have been partly due to this fact (Wittowski 1986). Statistical knowledge is rarely used by itself, but is commonly applied to subject matter. Thus knowledge about this subject matter needs to be included.

The prototype models the repetitive contact between entomologist and statistician at different stages of the design process, rather than treating the interaction as a once-only occurrence. Many other expert systems do not provide for this important aspect of advice-giving.

In addition to the production of a machine expert, the design of an expert system frequently makes a further contribution: preparing a detailed map of the field under study and thus structuring fields that may previously have been more diffuse or making them more transparent to non-experts.

Generalizing insect sampling plan design

Expert systems technology not only engages in an engineering task - designing computer systems that model expert human thinking - but it is also concerned with the analysis of concepts. The goal of conceptual analysis is a precise, formalizable catalogue of concepts, relations, facts and principles (Sowa 1984), resulting in a map of everything that makes up a particular field of enquiry. Conceptual analysis describes how the field of study is put together and how it works.

The present study goes some way towards this goal. It provides a taxonomy of the different types of experiments performed in entomology (Figure 3.1) and a number of decision trees that guide the user through the different stages of insect sampling plan design in the New Zealand apple orchard.

Some of the decision trees can be generalized to fit other environments (e.g., Figure 3.3), while the more specific decision trees (e.g., how many trees to sample per cultivar, Figure 3.10) provide information on environmental and insect-specific knowledge. For instance, Figure 3.3 summarizes the major steps in insect sampling plan design for the orchard environment. It can be applied to other environments by replacing orchard trees with other plants. Similarly, the decision process for the main sampling plan is essentially independent of environmental constraints. Both decision trees can be used by entomologists to guide them through sampling plan design. They could also be useful for teaching purposes.

Figure 3.9 and 3.12 are examples of statistical rules-of-thumb. Such rules-of-thumb are usually a product of long years of experience and are often not shared between experts within a field. They often represent short-cuts and are useful to record, as they provide knowledge that is not commonly found in text-books.

6.5 Conclusions

Insect sampling plan design is basic to much of entomological research, and expertise in this domain is scarce and valuable. Insect sampling plan design can, however, be modelled using expert systems technology.

In order to successfully capture the knowledge needed to design insect sampling plans, a technique - knowledge acquisition by simulating test cases - was developed. This technique overcomes the lack of test cases in this domain, and may be useful to acquire knowledge in other domains where test cases are not readily available.

The advisor-client relationship between statistician and entomologist was investigated. The interaction between statistician and entomologist was controlled by the statistician and can be expressed in a three-part model. This is a first step in modelling this relationship in an expert system.

The present study shows that insect sampling plans for particular environments can be developed and that the major constraining factors for each environment can be identified. Previously, only general guidelines (in the form of lists) on which factors might be important were available (Morris 1960).

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Acknowledgements

This study could not have been undertaken without the financial support of the University Grants Committee and IBM New Zealand. I was also financially supported by Lanes Horticultural Industry and the Malcolm Burns award.

I would like to thank my supervisors, Prof. D.R.Penman (Entomology Department - Lincoln University) and Dr.A. McKinnon (Centre for Computing and Biometrics - Lincoln University) for their support, encouragement, guidance and time throughout this project.

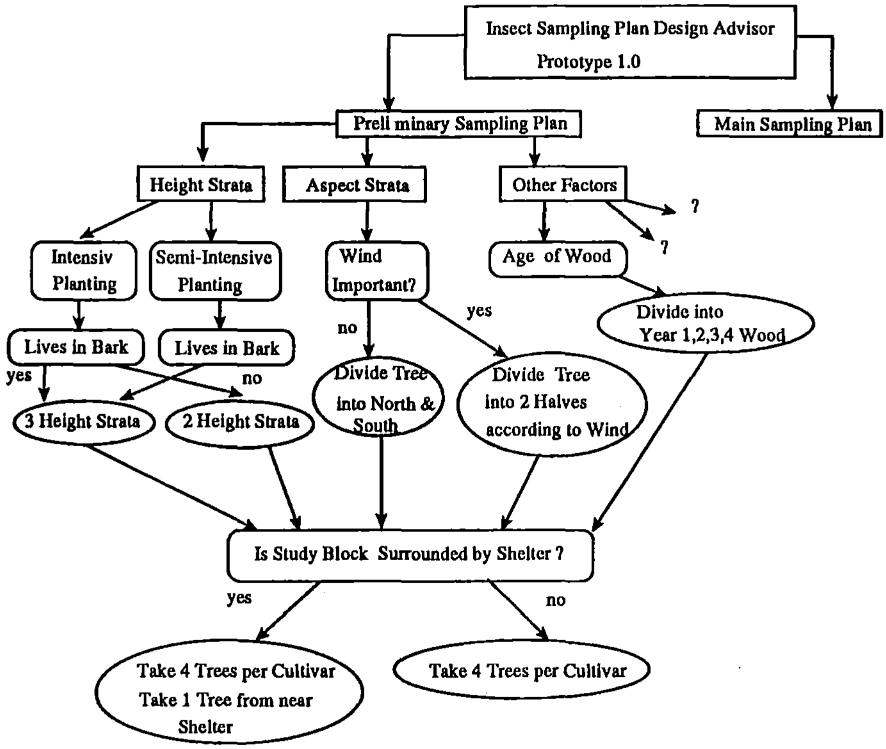
Various people gave assistance along the way and I would like to thank them all. Sue Worner (Entomology Department - Lincoln University) first suggested the topic. Dr. Jacqui Robertson (USDA - California) gave initial support and encouragement and later editorial comments on the finished product. Prof. Molly Stock (University of Idaho - Idaho) provided guidance, encouragement and editorial support throughout the project. Especial thanks goes to Dr. John Andrae (Department of Electrical Engineering, University of Canterbury), who not only read a draft copy of the thesis at very short notice, but also provided very valuable comments and criticisms. Without the untiring assistance of Chris Dyson (MafTech - Lincoln), my major expert the project would undoubtedly have faltered. Dr. Paddy Austin (Education Department, Christchurch) was an untiring consulting linguist. Helen Instone (Head of Registry Computing - Lincoln University) introduced me to the secrets of Prolog programming. Without the assistance of the interloans librarian, June Taylor, the present project would have been near impossible. Dr. Laurence Tobin, Bruce Robson (CCB - Lincoln University) and Dr. W. Kreutzer (Computer Science Department, University of Canterbury) kindly read and commented on draft chapters. Marnie Barrell (Entomology Department - Lincoln University) proof read the draft copy.

Members of both the Entomology Department and the Centre for Computing and Biometrics provided an atmosphere of support and encouragement throughout my studies.

Finally I am indebted to my friends who have supported me over the past years and to Jane, who has made the last year so much more enjoyable.

Appendices

Appendix 1 - Decision tree for the first prototype



Appendix 2 - Example interview and analysis performed on it

Example Interview

<u>Rye</u>
1 Yes, this time I brought an example
2 I brought the example of the FAL
3 and D.T. did a masters thesis on it
4 he had 3 objectives
5 3 things he wanted to establish
6 the first thing he wanted to establish
7 if this thing
8 this leafhopper was able to reinvade uncontrolled environments
9 he wanted to determine the temporal and spatial distribution
10 and the extent of the infestation in a commercial orchard
<u>Chris</u>
11 extent?
12 is that not the same as spatial?
<u>Rye</u>
13 he wanted in general to establish
14 how the thing was in an uninfested orchard/environment
15 to generally establish
16 what kind of temporal/spatial distribution it had
17 and then to see
18 how it worked in an uninfested environment
19 could it invade an uninfested environment
20 and to see
21 what was the behaviour in an commercial orchard
22 where presumably insects were depressing it
23 so that's really the problem we have
24 and now the idea is how to sample for it
<u>Chris</u>
25 What species of plant is it?
<u>Rye</u>
26 It attacks apples
27 and there are 3 types of damage
28 it feeds on the mesophyll
29 the adult feeds on the mesophyll
30 it leaves specks of excrement on the plant
31 on which fungal growth occurs
32 and do you want to know its life history?
<u>Chris</u>
33 yes, probably at some stage
34 and is it known
35 if it is particular which species of apples
<u>Rye</u>
36 nothing is known about that
<u>Chris</u>
37 because that would have been an obvious stratification
<u>Rye</u>
38 in fact no work has been done on it since the 1930's
<u>Chris</u>
39 why is there an awakened interest in it?
<u>Rye</u>
40 somebody wanted to do a masters
41 no, I think the idea was
42 what happens a lot in pest management

43 is that
44 you control these kinds of things for a long time with chemicals
45 and then maybe
46 when you switch chemicals
47 the new chemical doesn't control that kind of thing any more
48 and you have another outbreak
49 suddenly, it appears

Chris
50 you basically toughened it up over the years

Rye
51 so I think
52 the FAL was seen as a potential
53 potentially dangerous
54 inhabitant of the apple orchard

Chris
55 So when you talk about
56 the ability to reinvade
57 that's pretty much included
58 in that potentially dangerous aspect of it

Rye
59 Yeah

Chris
60 So, I guess
61 that its potential danger
62 may well relate to the differing backgrounds
63 under which the thing quietly has developed
64 or if that is the right word
65 or evolving
66 so that you can well have
67 spatial
68 or restricted to spatial distinctions
69 in respect to its ability to reinvade
70 it may well differ
71 according to what it has been exposed to.
72 If something has been applying a fairly stringent pest control strategy
73 such as these FAL that have survived there
74 may well be a degree more dangerous
75 than somewhere in an organic place
76 Yeah, I think that one thing I bear in mind
77 is that the potential danger to reinvade
78 may in itself vary
79 according to the history
80 so objective number 1
81 I expect it not to be constant
82 depending on exposure to the insect or pest
83 well, you're throwing me as a biometrician in the deep end
84 because you haven't come along and said
85 I want to do a survey
86 or a very detailed experiment
87 and gradually the penny drops
88 maybe I will feel it's an inappropriate level to attack it from.
89 The survey may or may not right thing
90 If you're throwing me in
91 I now have to consider both
92 the survey or the detailed experimentation

Rye
93 well, really we want to know

94 quite detailed information on
95 spatial/temporal distribution of all lifestages
Chris
96 that sounds like both
97 or everything
98 that sounds like pulling all the stops out
Rye
99 I suppose that is what Dave did
Chris
100 If little is known about the life history of the insects
Rye
101 Well, everything is known about the life history
102 It is known what kind of life history it has
103 we know it lays eggs
104 in the winter under the bark of twigs
105 and in the spring, nymphs appear
106 which turn into adults
107 and these adults then again lay eggs
108 but then this time on the mid rib/veins of leaves
109 and these turn into eggs/nymphs again
110 and in the last
111 before winter the adults lay again eggs under the bark
112 all active stages
113 the nymphs and adults
114 live on the underside of leaves
115 that much is known
116 and probably that much will always be known
117 about an insect
118 if it was a totally new insect
119 it obviously would be a totally different story
120 at the moment it's pretty much known
121 how it lives, where it lives and what it does
Chris
122 and the three types of damage obviously
Rye
123 and the eggs are quite small
124 0.5 × 1 mm
Chris
125 they can't quite easily be seen with the naked eye in situ
Rye
126 probably not
Chris
127 are they clustered
Rye
128 doesn't actually say
Chris
129 If we were going to do some serious egg count
130 we try to discriminate very accurately
131 what are our expectations to see them
132 do you have to bring them back to the laboratory
133 to look at them under the microscope
Rye
134 Yes, that's what occurs in this case
Chris
135 I feel
136 I would ask the enquirer
137 where he wanted to put his emphasis

138 rather than me having a lot of questions to answer
139 we can apply equal pressure to them all
140 but hopefully the person will give some guide
141 where the effort needs to be put initially
142 I would expect that it would not just be a once
143 seeing a biometrician
144 got all the answers
145 and never saw him again
146 that would be
147 if I wanted to guarantee a fairly strong probability
148 of meeting all the objectives
149 it would be an overkill in a massive way
150 so I am looking to establish a relationship with the entomologist
151 so that we gradually get the feel
152 of the resources needed
153 to achieve the various objectives
154 often people will come to me armed with that information
155 if we assume that we haven't got it for this one

Rye

156 what kind of information

Chris

157 The information of resources are available
158 and how difficult things are
159 and a ranking of the objectives
160 OK I want to get some structure
161 into which to look to optimize
162 if I optimize on a blank piece of paper
163 ....?

Rye

164 Well we have three orchards
165 one which is commercial
166 two which are non-commercial
167 abandoned, unsprayed
168 where this apple leaf hopper still lives
169 happily
170 cause it's not sprayed
171 so the resources are the usual
172 one person with all her time etc
173 I imagine the initial thing would be to work out
174 what is the spatial/temporal distribution in an unsprayed situation
175 then the same for a commercial, sprayed situation

Chris

176 Well, hopefully, that addresses the ability to reinvade objective
177 give ourselves a handle on whether there appears to be a difference
178 I guess, with these abandoned orchards they were abandoned because of the pest or for other reasons?
179 for other reasons
180 In fact initially ......

shows picture of orchard

181 abandoned orchard, unsprayed (Lincoln University organic orchard) and commercial orchard
182 they are approximately the same size
183 bad luck that the abandoned orchard got ripped apart

Chris

184 Well that is obviously useful ecologically
185 giving some answers in that area
186 well they might or might not be useful

Rye

187 so we have these three similar sized orchards

under different management systems
and all of which
contain all sorts of apples
the commercial contains three cultivars
so we can't really stratify on variety at all
cause there is a real higgledy piggledy

Chris

So there are different cultivars in different orchards
OK, but at least it gives us the opportunity
within an orchard
to find out
whether there are differences between cultivars
which is obviously important
in trying to relate different orchards
so, what other constraints
do you need to know

Chris

I guess I have learnt something already
the fact that you
home in on three orchards
as the key resource almost
suggests that, you mentioned temporal/spatial distribution
I though you might be considering
every apple tree in NZ as a possible sample unit
it sounds that is not your drive
that is a constraint
that I find somewhat helpful
in that having to plan
to sample every apple tree in NZ
would require obviously a lot of
knowledge, information, effort
which we are going to be spared
OK we have three orchards
which represent the range of environments
so if we home in on one of the orchards
first of all it's the different cultivars
these could well be confounded
by shelter, exposure
within the orchard
we might not find out successfully
whether there is a cultivar by different environmental interaction
possibly that not a difficulty in the approach we are taking
it is a fairly general question
we are trying to answer
we might say it appears that
there might be an environmental factor
different cultivars, start to think sampling within the cultivars
the temp within the cultivar
the spatial likewise
so we want to check out
that we can generate the kind of data we want
with other words check out techniques
techniques for data capture

Rye

would that be the kind of thing the entomologist would say
technique a, b, c would be used
or would you come up with the technique?

Chris

Well I guess in hindsight what tends to happen
that I will ask them what techniques they have got
and probably make some suggestions of ways how they might be improved
we often find
they've thought of these or tried them
or occasionally they say
we haven't done that
just if you like indulging in a bit of lateral thinking
rather than having a firm check list
a list of free thought
of the sampling we might not have thought of
they presented to me
as if the technique is not exactly
set in concrete, but
the knowledge they have about the appropriateness of a sampling technique

Rye

and do those techniques mean a lot to you in terms of statistics
or does it not really matter

Chris

Well, I try to relate
what I perceive the technique is going to do
what it's going to achieve
to the stated objectives
I see that very strongly
as a big component of what I'm doing
they might have a very flashy
very robust technique for measuring something
but if it's measuring in the wrong direction
then no matter how impressive it is
it's not of real use
I keep bringing the objectives back into the conversation
so that my understanding of the objectives
improves the objectives themselves
refined ?? should they
so more and more we are matching the sampling and the objectives
because at the end of the day
you obviously want to feel that
this is addressing exactly
as closely as possible
that's very much a threat that runs through the development of the sample
I guess it's a field I'm not familiar with
let's assume it is
I guess I might not have too many points of reference
I interrogate
finding out the detail whereabout the mites appear
how consistently they appear
how consistently they can be recorded
if you like
what appears to be a similar situation
get a feel for the repeatability of the technique for counting
or presence/absence
I guess we are looking at counting rather than presence/absence
are we? is that specified

Rye

I think we count (mean number/5 leaves we got here)

Chris

294 if a person would normally have established
295 that there was good repeatability
296 if you count 3-9 times you get essentially the same number
Rye
297 usually what happens
298 you pick the leaves, stick them in a bag
299 and take them home
300 that's repeatable
Chris
301 when you get it home
302 you take it through your system of counting
303 you get the same answer
304 obviously the number that you had when you
305 left the site plus
306 the number you have when you come to read it
307 may change
308 they may drop off, etc.
309 I think it's a question of how sticky the eggs are
310 if you know you have handled them carefully
311 and the eggs are sticky
312 it is reasonable to assume that they are still there
313 if you saw them dropping off in the field
314 you then run into a problem
315 obviously, well one would then want to say can you count them in the field
316 by taking the leaf off quite carefully
317 if the answer is no
318 then you are introducing a factor
319 which is a nuisance
Rye
320 Well in our case we have the eggs laid under the bark
321 which will stop them from dropping off
322 or the case of laid into the midrib
323 which will also stop them
Chris
324 So we can be quite confident
325 that we got the vast majority
Rye
326 The bigger problem is really how to see them
327 once we got them back to the lab
328 but that's really a problem of technique
Chris
329 Well that's where the repeatability comes in
330 well its biased as well
331 of course
332 I haven't pressed that one
333 until you mentioned it there
334 the bias is that
335 in certain environments you systematically miss them
336 so it's a a little
337 it's of great concern to me
338 that I become assured
339 that there is no bias
Rye
340 How could I assure you of that?
Chris
341 Well, clearly if nobody has come up with a technique for actually extracting all
342 of which that are there

and on one has realised
there are some which are still left behind
this is an area of unknowing
which we are not aware
I don't know how we're going to address that one
unless, I mean, you could put on to that by
say doing a life table study and
discovering that 50% of something has disappeared without trace
and you can't think of
any reason why
have we got in fact that count right
have to look at that again
and in fact by looking extraordinarily thoroughly
you discover that there are more under the plant tissue
so you have a naive count
which is the superficial one
and then you discover
clandestine one if you like
.....?
insect, I'm not aware
are not commonly known for that kind of subterfuge
so that unless ...
we might say well it's unconceivable
well in an idle moment
you might pull a leaf to bits
to see if you can in fact uncover any evidence whatsoever
that they haven't been in places
other than you thought they were
I would expect the entomologist
in looking at the interrelationship
between the insect and the plant
which he presumably has done informally at least
would have actually revealed
that the eggs or the thing gets further round than we thought
having got that out of the way
hopefully successfully
being assured, yes the eggs are laid on the surface
not buried or hidden away in some way
we proceed, with assuming
with the repeatability test
and find we score effectively the same number
and so at that stage we conclude
that the count as we record it under the microscope
is the count which was on the leaf, on the tree, in the orchard
clearly, there is always an element
a very small element of doubt
this is very often the entomologist will claim a 100% success or efficiency
or if it is less than 100
somewhat substantially less than 100
you find few people claim between 95-99%
which may be the truth
if we are starting to home in on some very very fine differences
but that's the kind of point that
will be brought up again
at the stage
that we next examine the techniques
because we have to sharpen it up

400 in order to hope to discriminate
401 in a way that will pick up fine differences
402 so we get a repeatable technique
403 which is unbiased
404 so we can translate microscope counts to in situ counts
405 so we approach a cultivar
406 not knowing .... find it or not
407 which got a whole lot of representative trees
408 we don't know where they are on the trees
409 we don't known when
410 well, we must have some idea as to when I suppose

Rye

411 Yes, well we know that they are on the trees in winter under the bark
412 we know that in spring they hatch
413 then all summer
414 till autumn again
415 they live on undersides of trees, basically
416 we know that
417 we know there are adults and nymphs
418 we know there are 5 stages for the nymphs
419 and so there is obviously no larvae
420 nymphs just look like little adults
421 do we need to know anything else?

Chris

422 I can't think of anything at the moment
423 well what ever time of the year it is
424 I presume the person wants to go out there
425 this afternoon or whatever
426 so that's the place we pick it up

Rye

427 so the person obviously wants to know
428 well when I say about the the temporal distribution
429 we want to know how many are there in January, in February, etc.
430 so that the temporal component
431 so we would have a sampling program that would go through the year
432 and then we want to know
433 well, whatever the spatial distribution means
434 I mean I discovered that's a big problem area

Chris

435 Spatially, well
436 the thing is whether its spatially within a tree or between trees
437 I mean I use the tree as a kind of pivotal unit here
438 for instance, I'm not sure that you are talking about spatially on a leaf
439 I mean there must be some level of fineness
440 beyond which you are not too worried about
441 whether it's the outer or inner end of the leaf
442 you might be I suppose
443 I suppose we are interested in whether the thing lives more in the outer or inner part of the tree
444 I think they often want to know
445 can we describe it by a negative binomial
446 or do we use a green's, whatever index
447 so that's one of the questions

Chris

448 Well, OK, what we'll do is
449 select a few trees
450 now, again, I suppose
451 it depends on what kind of

452 how much of a feel
453 do we really have a grip
454 where those beasties are within this cultivar
455 how strongly have they got hold of it
456 or whether there is more a focus
457 on what they are doing within a tree
458 this tends to make me
459 a lot of tree samples at a very low level per tree
460 or fewer trees samples more intensively
461 I'll look for some info on that
462 otherwise I just assume
463 to sample most trees thoroughly
464 I don't really want to lead you down the garden path
465 in terms of what we already know
466 so I'm looking for a lot of feedback
467 a lot of helpful indication
468 as to which way we're going to take it
469 whether we want to get 1 or 2 trees intimately
470 or get the picture
471 the average picture for the whole lot
Rye
472 I think we want to get the average picture
473 for the whole lot, in this case
474 maybe later
475 when we have done this thing
476 we would do the other thing
Chris
477 if its springtime
478 and we can actually see the mites on the leaves
479 if we couldn't see them at all
480 and we didn't know how widespread it was throughout this cultivar or this orchard
481 we wouldn't be in a very strong position
482 because basically
483 we've got to take a lot of bark
484 off a lot of trees
485 and cart it back
486 and hope that we got some positives
487 I don't see any option but doing this
488 for instance if we start in winter
489 which is the hardest
Rye
490 that's what we would do for the eggs
Chris
491 Well, sorry, the thing is if you started in autumn
492 and discovered that some trees are plastered
493 and others haven't got anything on them at all
494 I think it's not unreasonable
495 to assume
496 that the trees which are plastered
497 are much more likely to show signs
498 having eggs in the winter
499 than the ones that are not
500 if that is the case
??
Rye
501 So you are saying
502 it's a good idea

503 to start your sampling program when it's easiest to sample
Chris
504 where you get the best indication of uniformity or of lack of it
505 start sampling
506 if you like
507 when there is lots of evidence
508 evidence for presence/absence
509 let's assume we do that
510 and you can actually see them
Rye
511 yes, they are little hoppers
Chris
512 well the thing is to walk through the block (Rye shows picture 1)
513 Now, you walk through the block
514 and note where you find them
515 you're talking about whether it's in the interior or outside of the tree
516 so I think you may well divide
517 well, you would go up to a tree
518 and if you spotted one
519 saying, ha ha this tree got them or whatever
520 and look at the tree
521 and start to get some feel
522 where they occurred on the tree
523 and maybe have the impression
524 that they occur very strongly in the middle
525 but not so much on the outside
526 or not so much on the top
Rye
527 you wouldn't do it formally
528 you would just look for impressions
Chris
529 I look for impressions
530 to work out whether I want to implement strata
531 as far as the trees are concerned
532 I look at one tree
533 and find there is a little on the outside
534 and a few at the top
535 find another tree and find something similar
536 then I start to think
537 well, that gives me the feeling
538 I am starting to build an expectation
539 where most of them occur
540 I want some quantitative information on this
541 so I may well divide a tree
542 into 3-5 strata which could be the upper, the centre, well lower
543 the branches, which are
544 well it depends on the shape of the tree as well
545 it's, we assume it's an individual, central leader
Rye
546 yes, let's assume we don't talk about one of these fancy canopies
Chris
547 yes that would make it quite difficult to stratify because you only have one strata
Chris
548 so we might have an upper, central and lower
549 we are assuming that the tree is almost a lollipop shaped tree
550 I guess if they are very big trees
551 then the upper one becomes a nuisance

604 but something like that
605 where you got
606 well I wouldn't say that you take more than five strata
607 the idea of concentrating in the middle
608 is, guess, hopefully the trees have been grown
609 so that most of their bulk is reachable
610 fairly conveniently and
611 there for most of the tree is there
612 so you're
613 having looked at a few trees
614 that's how you are going to stratify
615 so you are going to obtain counts of adults
616 from a sample of leaves
Rye
617 why leaves, how many
Chris
618 Well, you said you wanted leaves
619 in your preliminary thing, ...
Rye
620 Are we still in the preliminary sampling design?
Chris
621 the preliminary one was to identify where they were on the tree
Rye
622 But don't you have to do a preliminary sampling
623 to work out what frequency distribution they follow
Chris
624 Well, yeah, preliminary
625 where are they occurring on the tree
626 well consider the tree as having five strata in your preliminary
627 well you can say 6 or 7
628 if you start getting into twigs and branches
629 if in that most preliminary you see if leaves are a correct assumption
630 or whether twigs or something else
631 if you clearly discover that a lot of them are on twigs
632 then on leaves
633 then we must go back to the drawing board
634 say, hey we have model
635 our biological model is at fault
636 so let's say they are on the leaves
637 as expected
638 and that they are fairly evenly distributed through the tree
639 so we can't dispatch with any of these strata
640 we then decide, I guess
641 on the apparent cost of whether we need to sample tops of trees ourselves
642 to do a lot more work
643 to derive a lot more information
644 which may not be in any sense
645 more helpful
646 than what we can get from a more convenient part of the plant and easy access.
Rye
647 When you decide on the preliminary sample
648 how do you decide which tree to sample?
649 Do you just pick random number.
Chris
650 The preliminary was just to walk through
651 and find some existing ones
652 we weren't actually worried

653 on which trees they were on
654 now when it comes to stratified sampling
655 we decide
656 well the thing we wanted to check ultimately
657 is the extent
658 a good coverage
659 that cultivar stand, where it was occurring
660 so you're going to make a statement
661 about an average level
662 a tendency to be more on one end than the other
663 I guess
664 variation from tree to tree
665 this kind of thing

Rye

666 So we select our trees more on a systematic way, really

Chris

667 I think one will bear in mind
668 that since we're looking for a general picture
669 we may well consider
670 doing all the trees
671 it's the trade off here
672 well you got so many hours to put in
673 on this
674 if you're trying to get the best overall mean
675 then you just divide your time by blocks
676 you then spend x on each tree
677 you get 90 sec per tree
678 and that's what you spend
679 I can't see any point in spending
680 180 sec on each alternate tree
681 the danger of that is
682 if it becomes ridiculous
683 and you only have 5 sec per tree
684 then no sooner you arrive and you're off again
685 if that is the case
686 then clearly you have to decrease the intensity of sampling
687 by which you get a meaningful
688 you're getting, in this case, a count
689 whereby you have not been frantically hurried
690 you've got time to do the job properly
691 you're not forced into a bias
692 which is generated by being hurried
693 that you get time to cover your sampling limit thoroughly
694 so what again, it depends
695 how easy they are to spot
696 you might do a little timing
697 before you get to that level
698 how long it takes to count a portion of the tree
699 which you defined by whatever
700 say we count this branch
701 which has got 50 leaves on it
702 and do it thoroughly
703 and spend 3 or 4 minutes
704 you don't know the answer yet
705 if any old branch will do
706 I guess it's at this point
707 the first kind of hiatus is

708 to whether you exhaustively count one or two trees
709 you decided let's say on 3 strata
710 as being practical
711 that you would count a few trees on the basis on the 3 strata
712 and you count a couple of
713 you might take a couple round the average
714 one highly infested
715 one poorly infested
716 and count them out
717 you pick representative branches from all around the place
718 and count all the leaves with hoppers
Rye
719 the only problem here is
720 that you actually have to destructively sample as it were
721 I think the hopper hop away
722 you have to take the leaf
723 put it in a bag
724 take it home
725 and then presumably kill the hoppers and count them
Chris
726 You can't do any in situ counting
Rye
727 No, I don't think so
Chris
728 You can only do presence, absence
729 a kind of gross ....
Rye
730 I think very rarely in entomology you can count in situ
731 because usually they run off.
Chris
732 So if we can't do that
733 that means this population is far more mobile
734 than I anticipated
735 Do we know
736 if they routinely leap from tree to tree.
Rye
737 I think what we know is
738 when you approach the tree
739 they leap off and then leap back
740 off into the air ...
Chris
741 Is that just a kind of token jumping
742 just a gesture
Rye
743 That's what it seems to be.
Chris
744 Do they jump to somewhere positive
745 you can see that quite readily.
Rye
746 They seem to jump off and jump back.
Chris
747 Well we can't say
748 here's a leaf with a hopper on it
749 here's a leaf with a hopper on before I arrived
750 you know it could well represent a very difficult piece of technical work
751 to assess how many there are
752 in an undisturbed condition

<u>Rye</u>
I think the technique is to use sticky traps
because of this problem
of the hoppers escaping,
because the eggs don't need
the eggs don't move
the other options are
leaf samples
sleeves cages, which I am not sure what they are
<u>Chris</u>
The other specific problem
one way or another
given that we were using the adults
as indicators to where they were
I guess the fact that they hop
certainly makes it easier
in terms of finding out where they are
you just approach your tree and watch
and you can quickly establish
whether they are right through the stand
or really aggregated
you can decide that pretty quickly
on the basis of whether you
what kind of distribution on a tree basis
from tree to tree you've got
you may even understand whereabouts on the tree
perhaps if you approach slow
and observe their tolerance before they leap
you can actually establish
whereabouts on the tree they are
quite easily
that's much less of a problem
than it was
it's a trade off
we've got less of a problem
where they are on a tree
but more in terms of our numbers
within the tree
if they are extraordinarily touchy
and you don't know where they jump
to stick traps out, sounds like a good idea
in the sense given that you can create enough surface area
to collect a reasonable number of them
whether you need to provoke them
to make them jump
or whether they will jump anyway
is information obtained by a little observation
10-15 minutes of watching a tree or two
where they normally exist
and see whether they move
if they don't move at all
your sticky trap mightn't work very well
except when you are there
we would have a very static situation
which is totally fouled up by your presence
I'm not sure if sleeves
you might consider sleeves then

808 given that you ....
809 depends if the thing can perceive sleeves
810 that it can't jump to safety
811 ...
812 back to literature what
813 singly mobile insect can you look at

<u>Rye</u>

814 Sticky traps, leaf samples and sleeve cages is what he did
815 some sticky traps
816 I imagine the nymphs wouldn't be able to escape
817 because they have got no wings
818 so they would be quite easy to sample because
819 of their inability to escape
820 and I imagine that adults
821 yeah, be used to sample adults sticky traps
822 and the nymphs leaf samples
823 and eggs leaf samples
824 also sleeve cages

<u>Chris</u>

825 It certainly appears counting the adults
826 may appear a bit problematic
827 sticky traps, I guess, will give you a relative figure
828 between trees for instance
829 but it might be rather difficult to say absolutely
830 so we might be faced with
831 we can't find a convincing count for the adults
832 we can get relative count
833 to mirror the later nymph stages
834 and possibly I mean
835 make some reasonable assumptions
836 of the later nymph stages that are surviving
837 I guess this depends on
838 what you know about predation
839 if it's a heavy number of predation
840 then the number of adults might be in a sense
841 not be very relevant anyway
842 if we assume that
843 almost all final nymph stages become adults
844 then it turns out that most of the adults get eaten by birds
845 basically we are interested
846 in getting back the number of eggs which are laid
847 obviously some relevance
848 to how many male and females there are
849 you might be able to work that out from the other end
850 from lab studies/control studies ..
851 so it depends how much emphasis you
852 as far as getting
853 establishing fairly thorough counts
854 on let's say 3/4 trees
855 infested, medium and couple of low ones
856 to get a representation
857 you can count
858 depending on the structure of the tree
859 let's say a quarter of it
860 you identify a unit, let's say
861 one branch as thick as your finger
862 you divide the tree up into these units

863 and take, let's say, every fourth one
864 and count, I don't know
865 if you need to count anything above the number of leaves
866 and take it back and count the nymphs
867 so you know which strata they come from
868 you get an estimate of the proportion of the nymphs on the tree which come from each strata

<u>Rye</u>

869 and obviously we couldn't do that kind of stuff in a commercial orchard.
870 They wouldn't be very pleased
871 if they found three trees without leaves

<u>Chris</u>

872 You only take a quarter of each one
873 given that you have to take something away
874 presumably you get some agreement
875 you remove as little of the material as possible
876 maybe, it depends how many trees there are
877 I suppose, you possibly want a minimum of 4-5 little branchlets per strata
878 again it depends
879 if you get the impression
880 that they are disgustingly variable
881 then that wouldn't do
882 I assume that they are reasonably uniform
883 for that level
884 so that will give you
885 a fairly rough figure
886 for the proportion which are in the various strata
887 and whether that proportion varies
888 with population density.
889 If you find it does
890 then you have problems obviously
891 you know if it appears that they fill up the tree from bottom to top

<u>Rye</u>

892 That's quite unlikely
893 considering the environmental condition would be different throughout the different strata
894 you wouldn't expect an insect in each different environmental condition

<u>Chris</u>

895 Well, they are very mobile anyway
896 If they got their by painstakingly crawling up the trunk
897 we've homed in in a reasonably informal fashion
898 we've homed in on the target strata
899 now when you're talking about the spatial distribution
900 we are now heading towards the spatial distribution
901 within the target strata
902 because if you like the bulk of them are there
903 and in terms of return for effort
904 that appears effort well spent
905 so we've got if you like
906 the bulk of the picture covered
907 we are aware
908 that they exist outside this strata
909 but in relatively low numbers
910 even so we haven't got a full count per tree
911 this is where I am going to operate from
912 clearly we might shoot ourselves in the foot
913 if we discover that
914 at some stage they move into one of the other strata
915 let's say, I am not sure if any of them are in the bark

916 presumably we know
917 whether this is just the bark of the trunk
918 or throughout the whole tree
919 if they came in all
920 if the eggs were all laid on the trunk

Rye

921 I mean that would be a thing to find out when
922 we look at the sampling of the eggs

Chris

923 but it would obviously be rather tragic
924 if it turned out
925 that the nymphs were all in the middle of the tree
926 while all the overwintering eggs were laid around the base of the tree

Rye

927 Why would it be tragic

Chris

928 If we assume that the same sampling scheme would carry us through

Rye

929 Can we do that?

Chris

930 We could do that
931 I don't know, it depends what people mean when they said they found them under the bark
932 I'm looking for some comment
933 if in fact it's then out the tree or not

Rye

934 Bark or twigs, the eggs are in the fleshy tissue of the upper layer of the bark of twigs.

Chris

935 We are not going to miss them
936 that the main thing
937 so we, sampling at a level of intensity
938 which we discussed in terms of time
939 and I guess in terms of material
940 in terms of now identifying trees
941 since we want to get a picture for the whole block
942 I would not consider choosing trees at random
943 unless I thought there was something funny
944 something systematic of the watching
945 that in fact the trees have been interplanted
946 with younger ones
947 the population density had been increased
948 that can give you a problem of younger trees between older trees
949 that kind of thing
950 all the same, I would think
951 that you would take alternate younger and older trees
952 as you went along
953 at whatever level of intensity
954 I don't myself set a lot of store
955 on getting an unbiased variance estimate
956 which demands a random sampling
957 when in fact, exposing myself
958 to having for a mean, which
959 is to determine what the distribution is
960 it has got an unbiased stand variation
961 I have a mean of 90 and an unbiased
962 ± 15
963 if I do it uniformly
964 I get a figure of 95

965 I don't know quite what its standard deviation is
966 except I know it's less than 15
Rye
967 How do you know it's less than 15
Chris
968 Because if I exclude the possibility that I have got a sample that's corrupted in some way
969 by virtue of some really cunning systematic underlying thing
970 which tends to effect
971 well for instance
972 let's sound rather naive
973 and don't notice there is a shelter belt
974 it's got big trees and
975 strictly ever so often there is a big gap between
976 them and there is the wind whistling through
977 there is no way
978 that I would sample only the trees
979 which are behind them
980 or the trees which are between them
981 so I can sample systematically
982 or reasonably systematically
983 having broken up the pattern of it
984 and I would say
985 I would want a kind of even input
986 right throughout this thing
987 the other way to do it
988 is of course to say
989 I am doing this randomly
990 I mean, I am going to take one tree
991 it depends on the disposition of rows
992 if the trees are very close together with rows
993 and the rows are miles apart
994 I might say I take one tree in four
995 and do it at random within each four
996 I might do that
997 because I am getting good coverage
998 now that's not random
999 in a strict sense
1000 clearly
1001 in terms of working out the spatial variance
1002 it gives methodologically
1003 a figure to work it
1004 I am taking charge of this sampling
1005 to make sure that
1006 the trees I am sampling
1007 cover it fairly uniformly
1008 so I am working against the random idea
1009 so I can't actually
1010 get this, but I am quite convinced
1011 that my standard error on this 95 is less
1012 could be then if it did it randomly
1013 because that has built into it an assumption
1014 that my coverage is not perfect
1015 I got nearer to perfection with this
1016 so I assume for argument's sake it's ten.
Rye
1017 Can you still work it out
1018 the standard error

1019 or are you going to pluck this number out of something

<u>Chris</u>

1020 You can derive it in the customary sense
1021 as a standard deviation
1022 you can call it, standard deviation
1023 well, I suppose it's not standard in that sense
1024 possibly it could be described as an estimate of deviation rather than standard deviation
1025 but it's got quite a lot of meaning
1026 and the thing is
1027 the randomized one is proof against idiocy
1028 we are assuming
1029 that there is no interplanting between old and young trees
1030 that it would be naive to ignore
1031 whether it was an old tree or young tree
1032 it may well be that the situation is very different for the two trees
1033 and if you don't control
1034 how many you get in a sample
1035 or what proportion of old/young ones
1036 that sounds like nothing to me
1037 that would just be a basis for stratification
1038 produce different answers ...
1039 but you tackle each one separately
1040 you, if you are relying on me
1041 getting the tightest answer for that
1042 I feel this is nearer to the truth than that is
1043 that is unbiased
1044 that is a bit of
1045 that is closer

<u>Rye</u>

1046 So why is it
1047 that random sampling is so pushed? That is what we always learn, you must do random sampling, nothing e

<u>Chris</u>

1048 Well, I disagree
1049 this number is all you get
1050 that one tells you
1051 gives you a feeling, how much confidence
1052 you have got in this thing
1053 but you can't relate it in a hard sense
1054 it depends, this is the target figure
1055 you gonna look at the variation in time
1056 I'm not sure whether
1057 I get the feeling
1058 if your approach was a kind of randomised approach
1059 that when you take a sample at January
1060 at February you take a different sample
1061 some of the trees would be common, other wouldn't
1062 and so you take a random sample each time
1063 that means you can look around the average
1064 because you know they are unbiased
1065 but a lot of your temporal changes are
1066 because of your change of trees
1067 reflected in this sure
1068 now if you were a strongly systematic person
1069 you probably take the same trees each time
1070 because then you say
1071 I have a much stronger handle on what happens
1072 temporally

by taking the same trees each time
and if you got kind of good coverage
you got a lot of trees you're looking at
say, 20-30 trees in your group
then I would feel that you're getting a pretty good handle on the mean
and you got a very good handle on the temporal thing
depends what you want these unbiased estimates for
the thing is that there is a price to pay for it
which is usually mentioned
but if you are doing it the random way
it's more or less foolproof
and people who are systematic
have been variously described as cunning(?)
and obviously cheats in some sense as well
you can work up a system that favours some number you've got
but I mean
strictly speaking you can still do that randomly
if you're that much of a cheat
you just carry on your randomization
till it picks out the sample you wanted
I can't really see ....
perhaps where the emphasis is
if I was sampling a good number of trees
I would sample the same trees
if I couldn't sample a good number of trees
the thing was very labour intensive
to get anything like
or let's say, when your sampling for eggs
the eggs are very rare
very rarely found
so your effort is pretty low
it's a bit far fetched
you've got less than 10 eggs/tree per six trees
then I would say switch trees
if you are just concentrating on six trees
you get a lousy estimate ...
you gonna have to reduce your expectations
or your objectives
make sure you visited most of the orchard by the time you're finished

<u>Rye</u>

Stop here.

Analysis of interview

Summary of major concepts

Rye 1-10:	3 objectives - - Is leafhopper able to reinvade uncontrolled environment? - Temporal/spatial distribution? - Extent of insect in commercial orchard?
Chris 12:	Queries - spatial
Rye 13-24:	Restates objectives: - How to sample for it?
Chris 25:	Queries - plant attached
Rye 26-32:	attacks apples, 3 types damage
Chris 33-35:	Queries - historical work done on insect
Rye 38:	no work done since 1932
Rye 40-49:	explains pest outbreak due to chemical control
Chris/Rye 58-82:	FAL toughened up over years (C) FAL seen as potentially dangerous (R) Ability to reinvade (C) Relates to different background development may lead to different spatial distinctions in respect to ability to reinvade.
Rye 95:	Clarification of objective e.g., detailed information on spatial/temporal distribution of all lifestyles
Rye 101-103:	explains life history of insect
Chris 135-156:	seeing a biometrician is not just a oncer gradual development of resources neede People will come with that information
Rye 158:	Queries - what kind of information?
Chris 158-163:	resources available difficulty of things objectives
Rye:	provides info on resources, priority of objectives
Chris 175-177:	Queries - why environmental differences
Rye:	shows picture of orchards
Chris 192-198:	different cultivars provide opportunity to find out whether they are important for insects
Chris 199-215:	comments on constraint of 3 orchards to sample all NZ orchard would require mo resources

Chris 216-231:	3 orchards = range of environments but best to start with one - can we pinpoint cultivar by environment interaction
Chris 234-236:	entomologist usually suggest appropriate and possible technique for data capture
Chris 257-276:	queries - is technique going to achieve stated objectives?
Chris 277-290:	where do insects appear? how consistantly? respectability of technique
Rye 298-301:	explains technique for this insect
Chris 302-324:	queries - how good is technique
Chris 327-342:	the problem of bias - is there possibility for insects to get missed? will technique extract all the insects there?
Chris 412-423:	reiterates life history
Chris/Rye 425-432:	what is temporal distribution - how many there are through year?
Chris 433-441:	spatial distribution occurs within and between trees tree is pivotal point level of finess? tree, branch, leaf
Rye 442	objective refinement - does insect live in inner or outer part of tree?
Chris 447-468:	either select a few trees and focus on what happens within or sample many trees low level
Chris 506-512:	start sampling when - lack or not of uniformity - lots of evidence for presence/absence
Chris 514-564:	walk through a block and note - where to find insects - any indication where to implement strata? - usually 3-5 strata, e.g., upper, centre, and lower or north, south, central, depe on tree shape
Chris 573-600:	north/south part of tree-different temperatures check row orientation do trees intertwine?
Chris 617-662:	preliminary sampling steps: - identify where on the tree they are - test whether sampling leaves okay as sampling unit (i.e., do they actually live there) - assume evenly distributed - no strata - work out opportunity cost of sampling tops of trees versus not - stratify - is it more on one end of orchard?

	- select trees systematically
Chris 663-680:	ideal to sample all trees, better 90 sec each tree rather than 180 sec on every other
Chris 705-720:	Take 3 trees stratify middle, low, high take representative branches
Chris 843-873:	Representative count of 1/4 tree until different strata identify unit, divide tree into it and take every fourth one, but minimum of 4-5 per strata
Chris 874:	the more uniform, the more samples needed
Chris 890:	home in on target strata informal fashion
Chris 930-940:	make sure we are not missing eggs if trees interplanted take alternatively young/old ones
Chris 950:	random sampling = unbiased variance estimate systematic sampling = standard deviation lower mean more correct random sampling caters for possibly corrupt sample
Chris 950-:	long discussion on random vs systematic sampling

Information volunteered by Rye

- objectives (1-24)
- type of damage (27-32)
- historical information (38)
- life history (101-121)
- picture of orchard (179)
- reiterates case (183-191)
- problems with eggs (327-329)

Information requested by expert

- plant species (25)
- damage (35)
- why interested in insect (39)
- type of experiment (83-92)
- life history of insect (100)
- egg details (125-127)
- resources available, ranking of objectives, difficulties (158-)
- why use abandoned orchard (177)
- counting for just presence/absence (291)
- sampling technique possible in field? (320,325)
- where in tree is insect (405-411)
- timing of sampling (424)
- type of spatial distribution interested in, i.e., within or between tree (436)
- level of finess (437)

Possible rules

- If a particular cultivar is obviously damaged - stratify
- The more not uniform - the more samples

- If trees interplanted (old/young) take alternatively and predetermined densities.
- The tree is the pivotal point

Further questions

1. What shapes of trees are possible?
2. Which strata associated with which tree shape?
3. What kinds of insects cannot be sampled in situ, i.e., question of mobility.

Major areas covered

objectives - need ranking
damage types
reason for it
life history
resources
techniques available
knowledge on how plants/insects interact
repeatability of technique
problem of bias
random vs systematic

General impressions

Some information needed to be restated several times.

Some information was misunderstood and led off on unproductive tangents.

Objectives of interview

Get a preliminary sampling design

Was objective met?

To some degree, but needs further clarification.

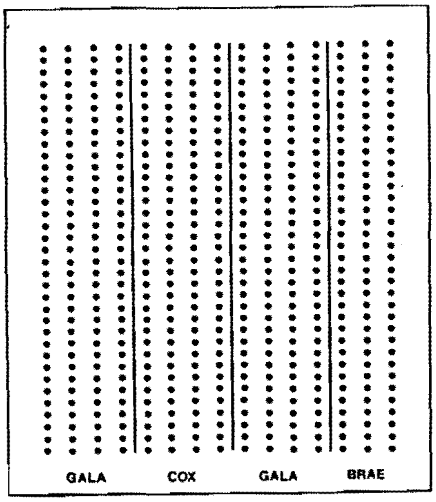
New objectives

Questions on:

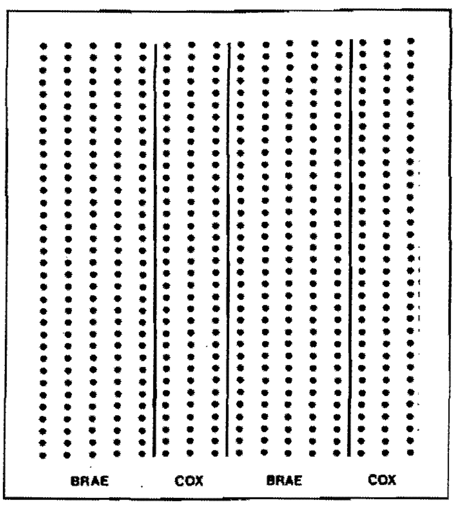
1. Measures of dispersion.
2. Sampling of overwintering eggs with reference to height, aspect and age of wood.
3. Sampling for summer eggs.
4. Sampling adults.

Appendix 3 - **Orchard layouts used in generating hypothetical test cases**

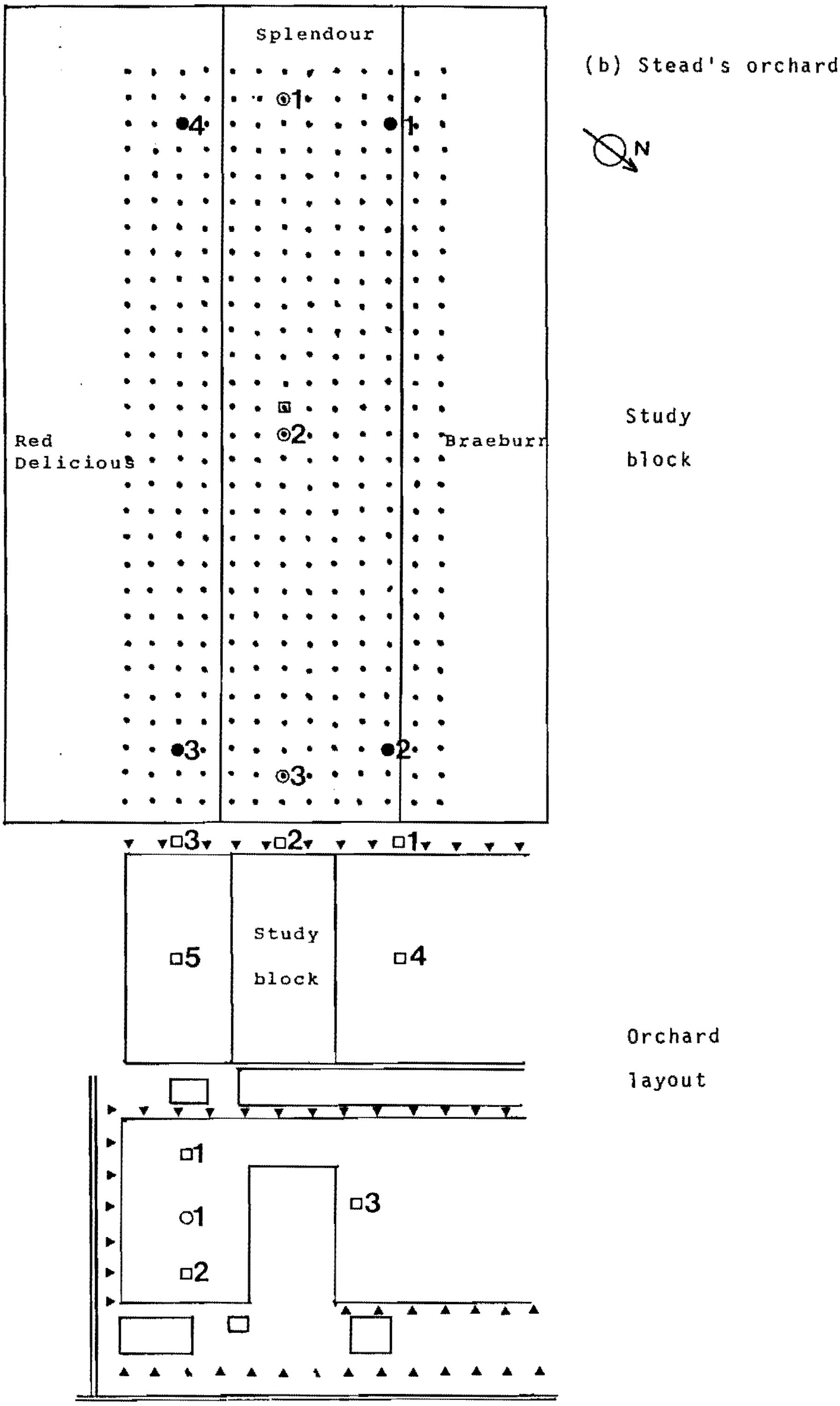
Orchard 1



Orchard 2

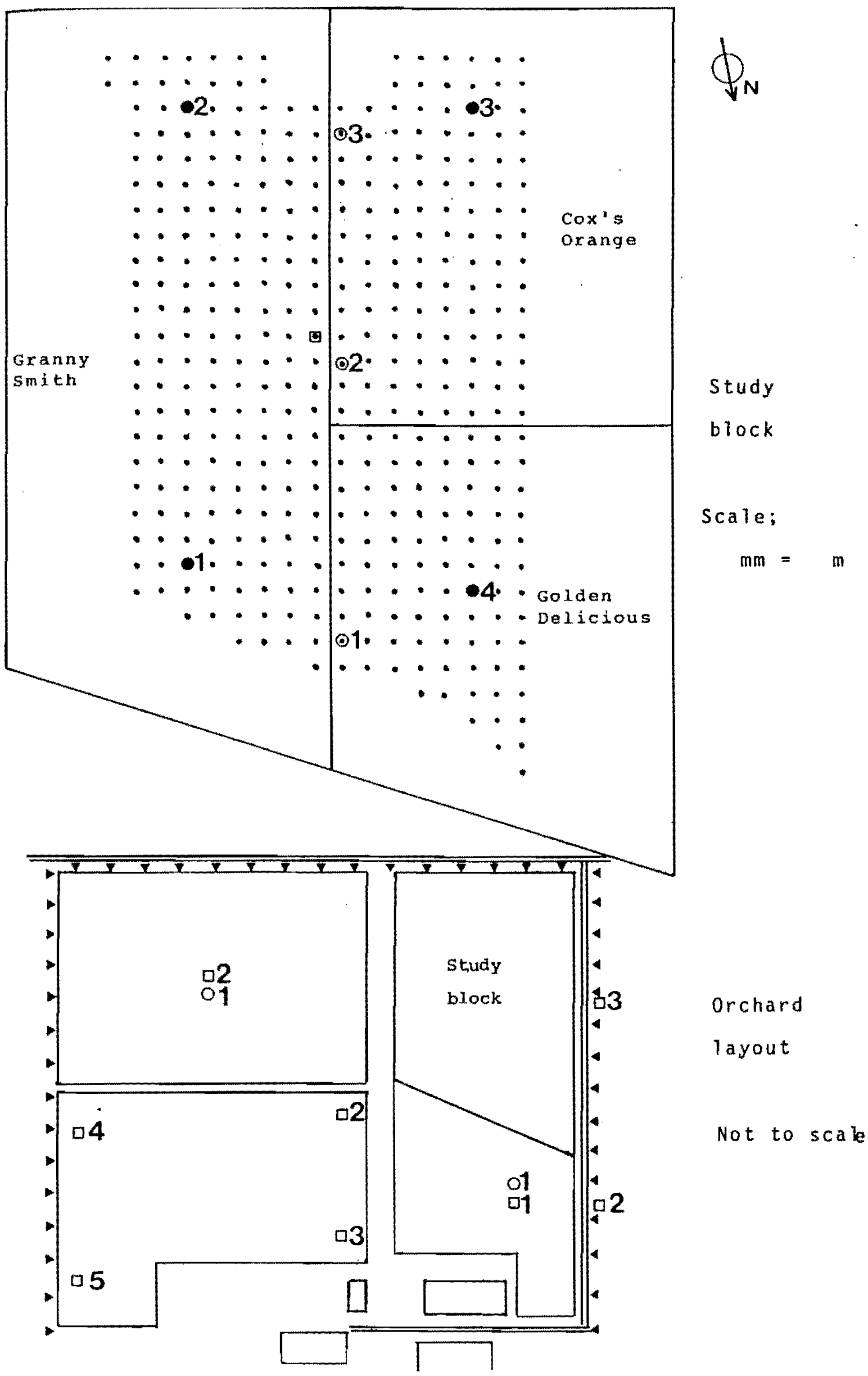


Orchard 3


Splendour
(b) Stead's orchard
N
1
4
1
Study
block
2
Red
Delicious
Braeburn
3
2
3
3
2
1
Study
block
5
4
Orchard
layout
1
1
3
2

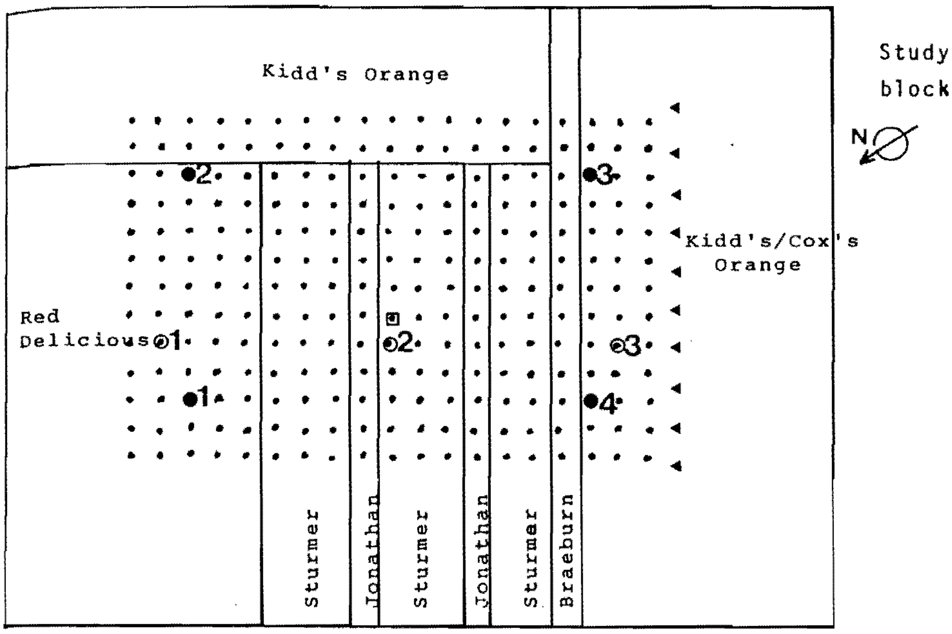
Orchard 4

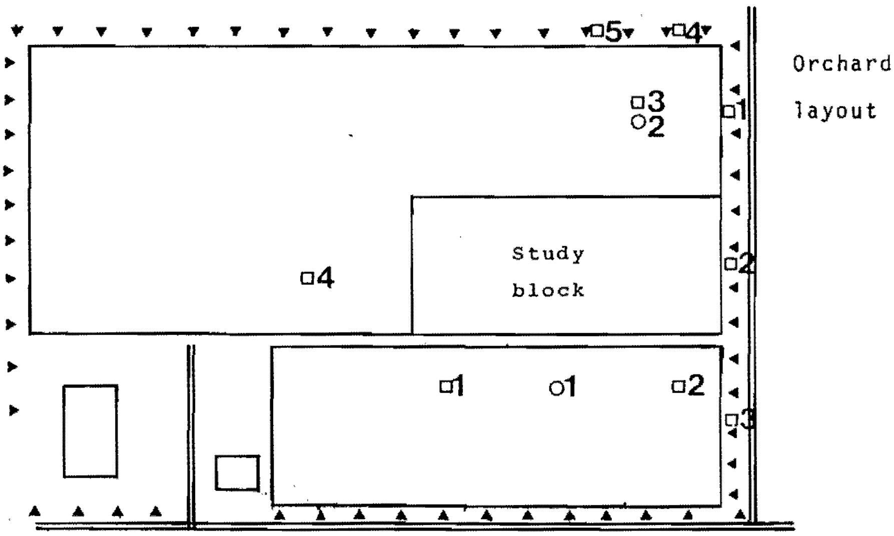
(2) Commercial orchards - (a) Clark's orchard



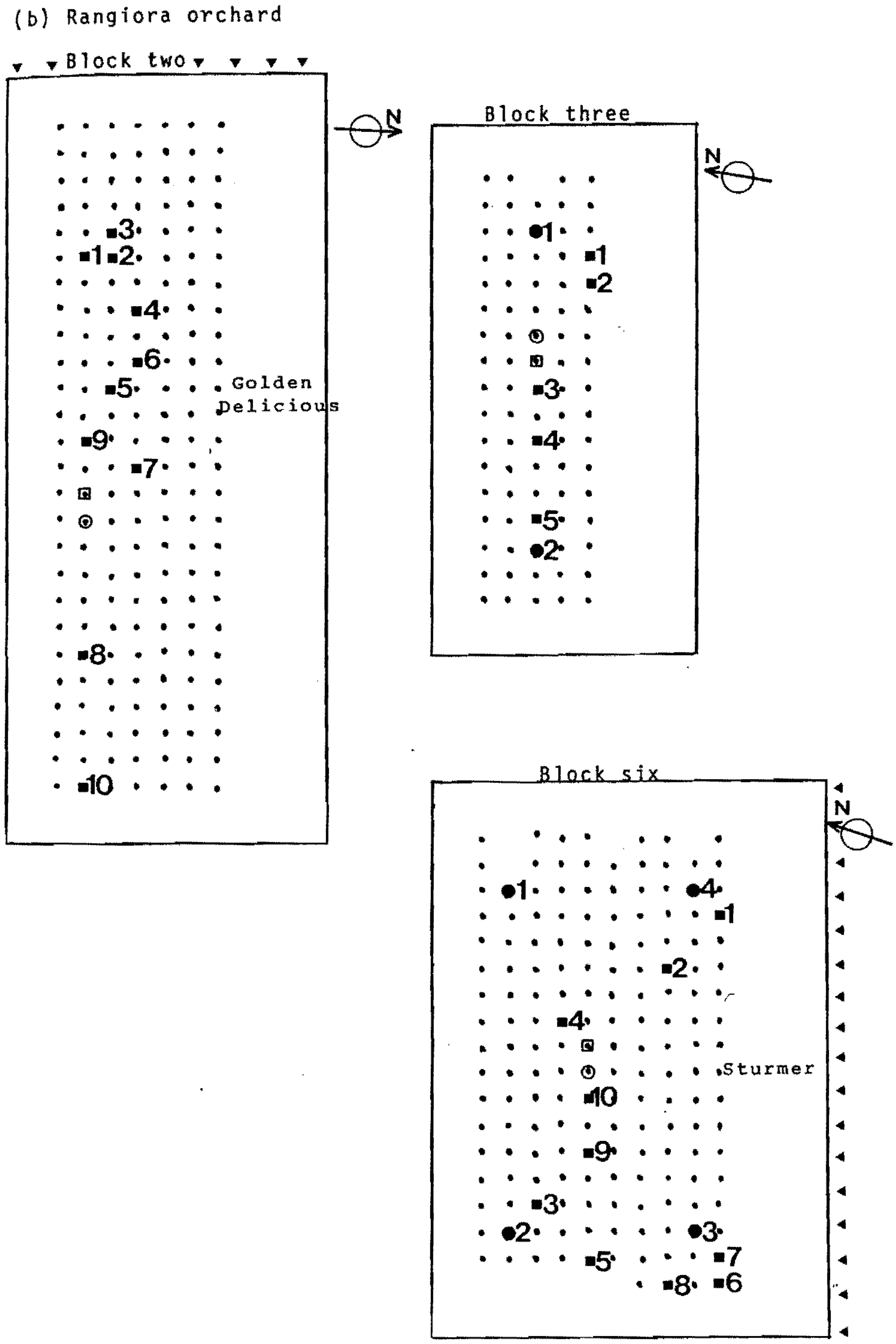
Orchard 5

(c) Washington's orchard

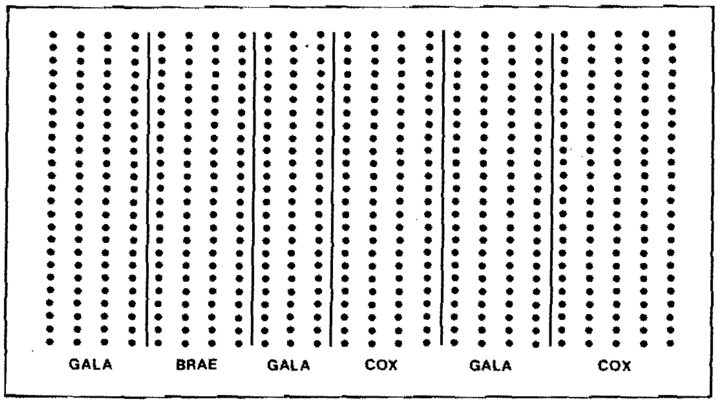




Orchard 6

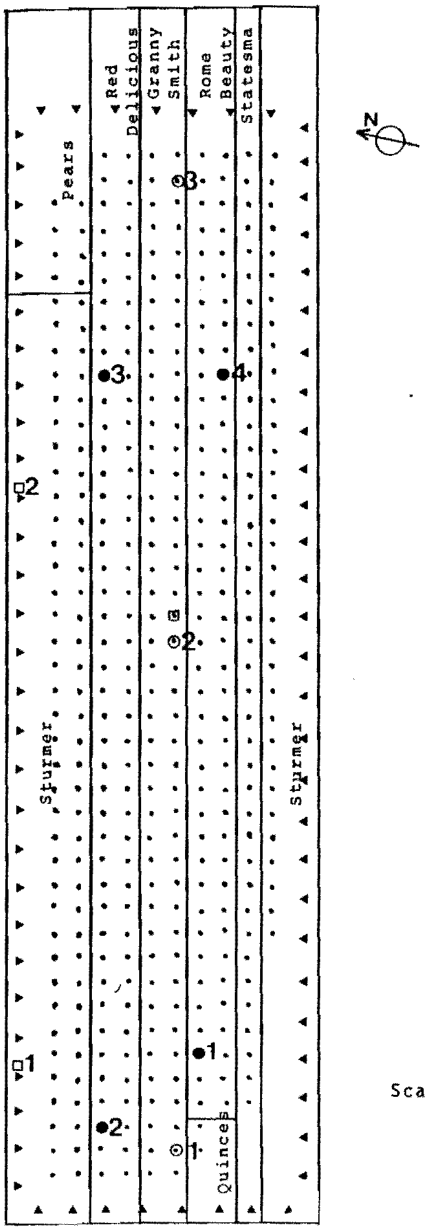

(b) Rangiora orchard
Block two
Golden
Delicious
Block three
Block six
Sturmer
N

Orchard 7



Orchard 8

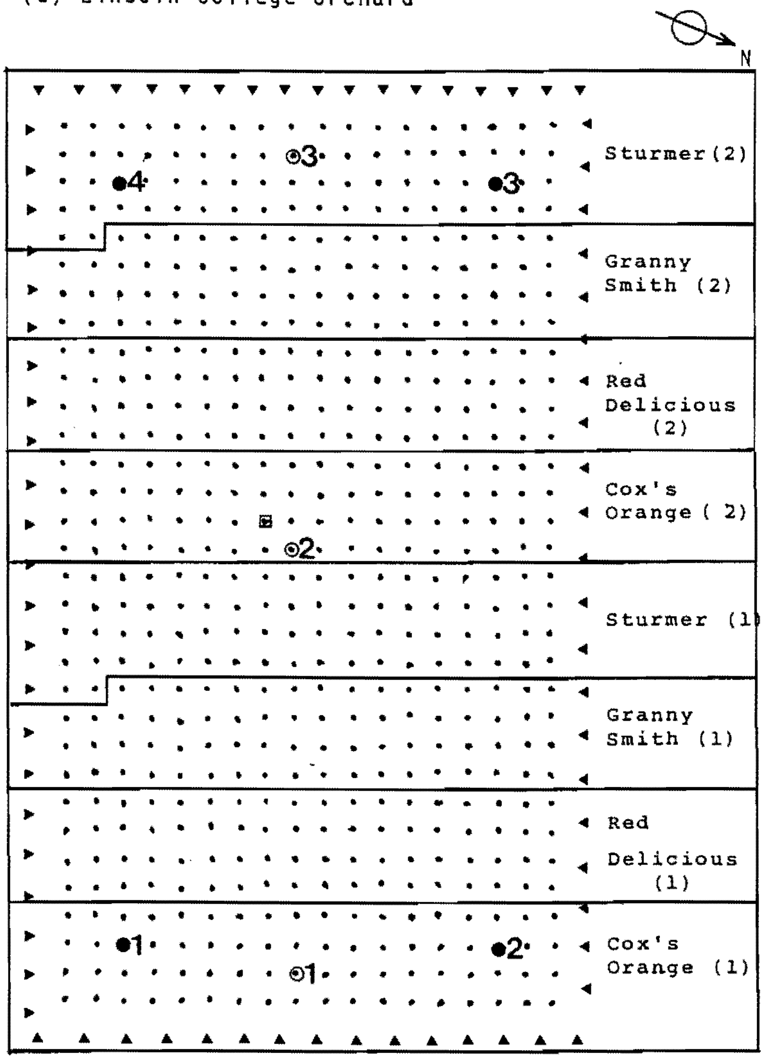
(1) Abandoned orchards - (a) Collins' orchard



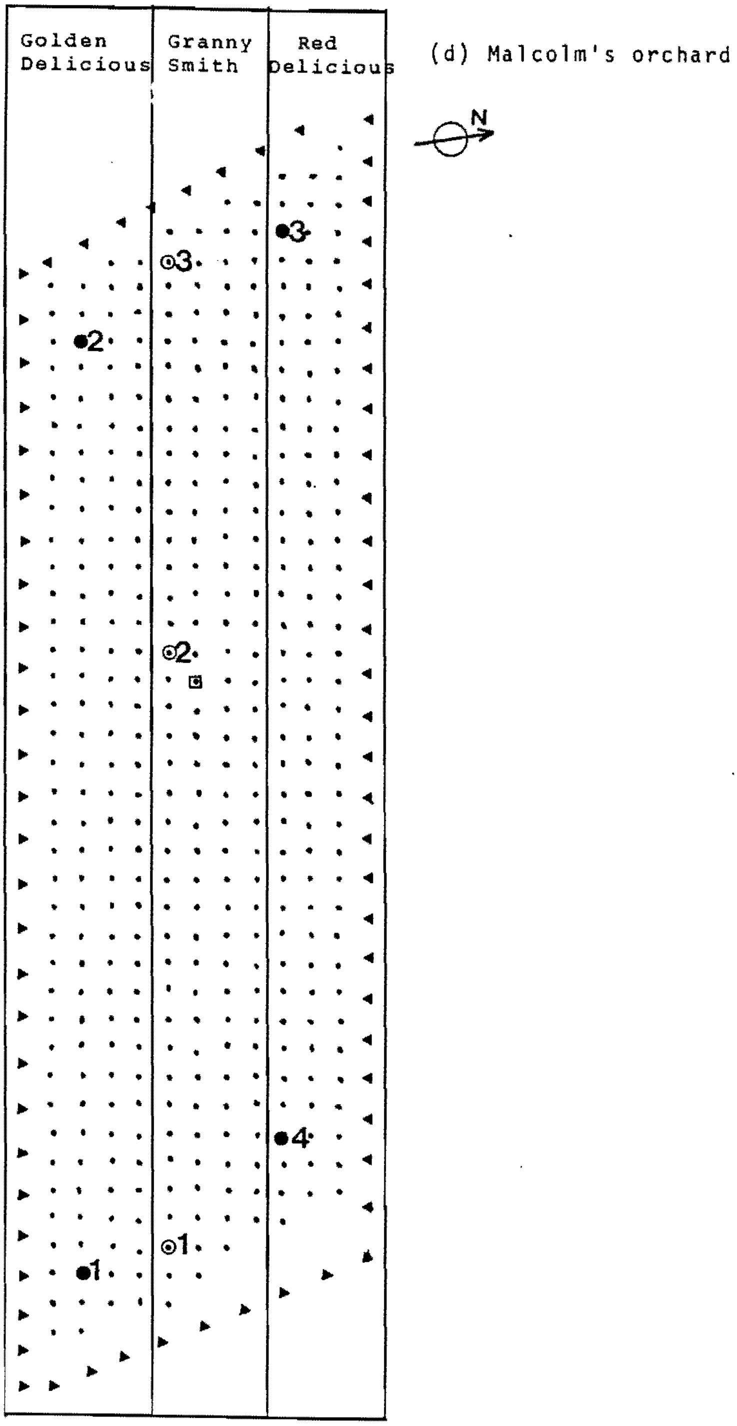
Scale 14 mm = 1 m

Orchard 9

(e) Lincoln College orchard



Orchard 10


Golden Delicious
Granny Smith
Red Delicious
(d) Malcolm's orchard
N
1
2
3
4

Appendix 4 - Sample data set for orchard 6

Note: All numbers refer to insects sampled per sampling unit.

Raw data:

height	aspect	gala			golden			sturmer			mean
top	N	2	12	4	1	3	2	0	1	1	2.9
	E	4	12	1	0	1	1	1	0	2	2.4
	W	0	23	0	2	2	1	2	1	1	3.6
	S	0	11	0	0	2	0	1	2	1	1.9
bottom	N	1	11	1	2	2	5	2	3	0	3.0
	E	1	2	0	0	3	1	1	0	0	0.9
	W	0	10	2	1	1	4	2	1	1	2.4
	S	4	1	1	0	0	1	1	1	1	1.1

Tree data:

tree	1	2	3	4	5	6	7	8	9
mean	1.5	10.3	1.1	0.8	1.8	1.8	1.3	1.1	0.9

Cultivar data:

Cultivar	mean	standard deviation
gala	4.29	5.834
golden	1.49	1.318
granny	1.08	0.776

Height data:

	mean
top	2.69
bottom	1.86

Aspect data:

	mean
north	2.94
east	1.67
west	3.00
south	1.5

Appendix 5 - Essay on sampling design.

Sampling for Insects - a Review of General Principles

1. Introduction

Sampling insect populations is one of the basic activities in entomological field research. Rarely can all insects in a given environment be counted, instead the estimation of the population size is achieved by sampling the target population. Numerous techniques are available for this purpose, but as Morris(1960) points out, the principles of population sampling are universal. Techniques necessarily differ according to diversity of lifecycles and habitat of the insect and objectives of research.

2. The objectives of sampling.

In order to design an insect sampling plan for a field situation the researcher must be very clear about the objectives of her research (Southwood 1976). Objectives can be placed into several categories (Graham and Stark 1954) :

1. Qualitative determination of insects present in a given area.
2. Quantitative evaluation of the population status in an area, e.g., determination of population levels.
3. Determination of population dynamics.
4. Investigations into the ecology of a species, e.g.; determination of zones of abundance.

Morris (1960) more concisely divides sampling into extensive and intensive sampling. Extensive sampling is designed to predict damage of insects and is concerned with the distribution of insect over a larger area. Intensive sampling involves continuous observation of a population of insects in the same area, usually to determine the causes of fluctuations in the population size or to construct lifetables.

3. Components of sampling design

Morris (1960) names the following components as common to all insect sampling plans:

1. The spatial distribution pattern of the insect.
2. Sample size estimation or magnitude of change to be recorded.
3. Selection of the sample universe.
4. Definition of the sampling unit.
5. Distribution of the sample unit in time and space.
6. Selection of the unit of measurement (only important when not counting).
7. Major sources of variance.
8. Cost efficiency of sampling method.
9. Biology of the insect and knowledge about their habitat.

In order to determine some of these components, especially spatial distribution and optimal sample size, a preliminary sampling program is necessary. In a preliminary sample different sampling methods, sampling units, and sizes are compared for their cost efficiency, statistical suitability and required precision. Size, nature and arrangement of sample units can all have effects on the data sampled.

The preliminary sample also sheds light on the spatial distribution pattern of the insect under investigation. It is a major consideration of any sampling procedure (Wilson 1976) as it influences sample size, sample unit and spatial placement of the sample unit. Types of spatial distribution observed among insects fall roughly into three categories: uniform, random and aggregated. Statistically a number of frequency distributions describe these spatial patterns mathematically. Random spatial patterns can be described by a

Poisson distribution. An aggregate spatial distribution follows one of the contagious distributions e.g. negative binomial, binomial, Neyman type A, Poisson binomial, or double binomial (Ruesinck 1980).

The habitat in which the insect to be sampled occurs is usually referred to as the sampling universe. Its extend must be clearly defined.

The sampling unit should be representative,stable, lend itself to a conversion to unit area and be easily delineated in the field (Morris 1955).

The level of precision required is closely linked to the magnitude of population change one wants to record. Southwood (1976) suggest 25% to detect population changes for damage assessment and control studies, while for life-table studies a higher level of accuracy (10%) is advised.

Most statistical techniques require sampling data to be collected in a random fashion so that unbiased estimates of the population parameters can be calculated. However in entomological research the use of stratified random sampling procedures is most common. Stratified random sampling is often more cost efficient, biologically more meaningful (Morris 1960) and minimizes the variance (Southwood 1976).

4. Considering the biology of the insect and it's environment.

Before even preliminary sampling can commence some information about the lifecycle, habits, environment etc. of the insect must be obtained. An important aspect of insect sampling is the tendency of insects to change its spatial distribution with its movement through its lifecycle e.g. aggregated eggs, randomly dispersed larvae and adults. The high mobility of insects and their often small size may present further sampling problems. In general it is advisable to sample the stage of the insect that is the least mobile , most visible and easiest to identify. The environmental conditions under which the insect lives must be precisely defined as the cop or plant represent the substrate from which the insect is to be extracted. Furthermore and understanding of the type of injury and damage to the plant and the response of the plant is, in the final analysis, the practical justification for most sampling programs, especially in pest management (Kogan and Turnipseed 1980).

References

Graham, K.; Stark, R.W. (1954) Insect population sampling. Proc. Ent. B. C.(51): 15-20

Kogan, M.; Turnipseed, S. (1980) Soyabean growth and assessment of damage by arthropods. p.3-29. In; Kogan,M, Herzog, D. (Edt.) Sampling methods in soyabean entomology. Springer, N.Y.

Morris, R.F. (1955) The development of sampling techniques for forest insect defoliators with particular reference to the spruce budworm. Can.Zool. 33: 225-291

Morris, R. F. (1960) Sampling insect populations. An.Rev.Entomol. 5: 243-264

Ruesinck, W. G. (1980) Introduction to sampling theory. p 1-78 In: Kogan, M.; Herzog, D.(Edt.) Sampling methods in soyabean entomology. Spinger, N.Y.

Southwood, T.R.E. (1976) Ecological methods. Chapman and Hall, N.Y.

Wilson, L.T. (1985) Estimating the abundance and impact of arthrpod enemies in IPM systems. p.303-323 In: Herzog, D.C. (Edt.). Biological control in agricultural IPM systems. Academic Press, N.Y.

Appendix 6 - Scenario.

Imagine you have just landed your first job as an entomologist. You have been appointed to the position of a research entomologist at Lincoln.

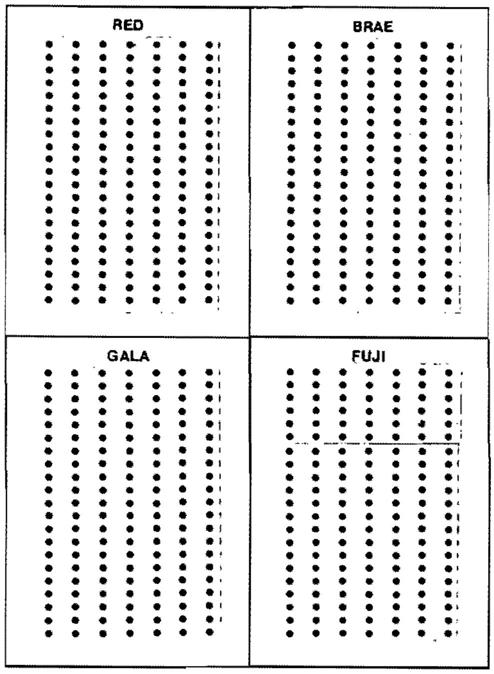
Your first task is to investigate the relative population level of xxxx. Your employer is especially interested in its yyyy stage.

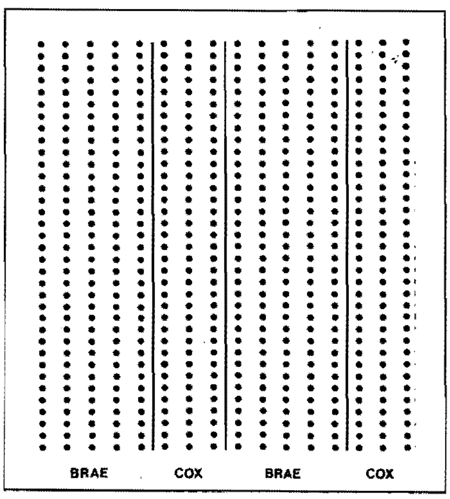
The resident statistician will assist you in designing the appropriate sampling plan. S/he is an expert in statistics, but knows little about the biological details of the insect.

To make you assignment easier you have also been handed a folder that contains the following:

- A plan of the orchard
- Some information on the insect
- A statement on how insect sampling is viewed in this organisation.
- An initial checklist for sampling plan design. This checklist is used to make sure the entomologist comes to the first meeting with the statistician with all the essential information on the insect.

Appendix 7 - Orchard layouts used in discourse analysis experiment.





Appendix 8 - Shortened transcript protocol.

The transcript protocol is a shortened form of the protocol developed by G.Jefferson (Sacks et. al 1974). The following transcript symbols were used:

//	Point at which a current speakers talk is overlapped by the talk of another speaker. A multiple overlapped utterance, is followed, by the talk which overlaps it.
(=)	Indicates 'latching' - no interval between the end of a prior and the start of the next piece of talk.
(5)	The number in parentheses indicates pause (elapsed in seconds.).
(?)	no 'hearing' by the transcriber was achieved.
(())	Features of audio material other than actual verbalization that are not transcribed.

Appendix 9 - Instructions to participants.

Dear Participant,

i have finished transcribing the conversation between you and the other participant. As a final step in this experiment I am asking you to complete the following two tasks for me:

1. Read carefully through the transcript. As you read through it try and give general labels to each group of coherent bits of conversation. For instance often in conversations we find parts that can be called greetings, or if you are discussing with somebody what you did last night, you might start with 'made a cup of coffee when i got home, rang friend, made another coffee, watched the news, had a shower, left home, visited a friend etc.'

Basically we are looking for descriptive terms of what is being talked about.

2. On the second reading I want you to group these labels into larger groups. For instance to continue the above example you might have the labels 'things i did when i got home' and 'things i did after i left home'. In scientific papers the larger structures/labels are usually introduction, material and methods, results and discussion.

How to do it: whenever you find a group of words that can be summarized by a label, write the label on the left side of the group of words and mark the beginning and ending with a curly bracket.

An explanation of some of the transcription symbols used to capture certain aspects of speech that are not obvious from writing down the words. For instance (=) means that there was no pause between what one speaker said and the next one (latching). Cross-hatches (//) means that while one speaker spoke the other one started speaking as well. A question mark means that i could not hear what was said. A number in brackets means a pause of so many seconds.

Well i hope this all makes some sense. Thanks a lot for your time and help.

Appendix 10a - Example interaction between statistician (C) and entomologist(T).

Note: This transcript has been edited for clarity.

1T: What I have to do is to investigate the population level of light brown apple moth and we want to know about the larval stage. This is a plan of the orchard that we that we are sampling from and I want to know how to do a preliminary sample. Just to find out, you know, if we need to carry on with this is or if the sampling method is ok and stuff like that.

2C: Right and you gonna sample it initially at some sort of ehm peak time in relation to the larvae.

3T: Yes, yes.

4C: Like you know.

5T: (=)Yes, I think the springtime is the best, yes.

6C: Right, (2) ehm, now this is a single orchard with these different varieties ?

7T: Yah.

8C: And are these varieties gonna be influencing your densities of your larvae ?

9T: Well we don't know.

10C: You don't know, you you wanna see, yeah, right and how do you sample when you are actually, if we lets say pick out a tree how do you sample that ? Do you

11T: Probably take, well whatever, like we can take individual leaves and look at then or we can take a leafcluster and look at that or we can take random leaves // or
C: Right

12C: And you just look for the presence or // absence of this thing ?
13T: Or you can do the whole tree

T: Ah, yeah

14C: Yeah, so any sample you take you either have a yes or no ?

15T: Yeah

16C: Right and your final outcome, what you actually want to say is that its present and what x percent of these trees its present in, such and such a density, how are you gonna sort of phrase your outcome

17T: We want to know after we have done this preliminary sample its present in enough numbers to carry on with the experiment, whatever we gonna do // suppose it will be density, won't it
C: Some sort of ?

18C: Right

19T: Yeah, yeah

20C: Ehm, obviously you have some idea even if you cant say what it is what a sufficient density would be

21T: Yeah

22C: Yeah

23T: Yeah

24C: Right, now do you have any background information on (3) ehm the likely, anything on the likely densities or you know how much this thing varies between trees or anything of this sort of stuff or is this totally preliminary so you just trying to find out ?

25T: Yeap totally preliminary its the first initial // sampling without anything
C: Sampling right

26C: ? so you have got 21 trees this way // and these are the numbers of rows
27T: Yeah

T: Yeap

28C: Right now you are obviously gonna be limited by how many samples you can handle, otherwise you'd sample the whole lot

29T: Mmh

30C: Aren't you, yeah, you have two levels of sampling you've got variation within each tree and then you have got variation between each tree and you obviously want to see if there is some difference between varieties as well so you got three levels of variation, here within a tree between trees and then between trees in different cultivars so effectively what we are do is take this as a sampling unit for several species // the variety of apple // and you just repeat that in each of these
T: Mmmh
T: Mmh

31T: Oh yeah ok

32C: Ehm now ok if you were to take a cluster of a leaves // em how many clusters is it gonna be reasonable for you to assess ? Obviously we don't want to destruct the tree completely, but you know how many is it practical to actually gather ?
T: Ehm

33T: Well, I suppose just as many as you think is necessary

34C: I think it will be quite crucial that when you come to your sampling you do them all within a very limited time period so you dont get any change in time and larval density // so you virtually want to do the whole lot in a day
T: Yeah yeah

35T: You do

36C: Ehm if you gonna assess leafcluster you strip that leafcluster off and do you take it away or can you do it in the field ?

37T: Well we could do it there or take it away

38C: Right, but you have to strip it off the plant ?

39T: Yeah I suppose you would, yeah, to get into it ah you probably have to take it away because the very small ones are right down to millimeters so you have to look at them under the microscope, so you probably have to take them back to the lab

40C: Right

41T: Mmh

42C: Ok, right, well that will restrict my numbers, because I mean you need plastic bags or something for every one // you have to bag them all up and label them were they came from all that sort of stuff ehm right all the trees are approximately the same sort of age so they are approximately the same size ecetera
T: Mmh

43T: Yeah

44C: Yeah

45T: ????

46C: And does the larval density move around, you know within a tree they more likely to be at the top of the tree bottom of the tree some side you don't know ?

47T: I think ehm, I think its fairly random all over the tree

48C: Right might pay to check that you can do that what I suggest you do then ehm first of all work out to approximate numbers of tree and then we randomly pick those and then stratify within each of one of those blocks and then what I suggest you do is you it might be a little awkward you might need ladders but we actually we actually break the tree down into components // obviously they gonna be on leaves so some sort of centre sampling is not really appropriate but I would suggest we take a sort of left and right and a top ?? get some sort of idea of variation within a tree but if there is some sort of systematic variation lets say they are all on the sunny side or they are all on the top we will be able to work that out subsequently
T: Mmmh

49T: Mmh

50C: Ehm ok, now we better work out whats a reasonable type of number for you to sample, so we got 4 blocks x trees by 3 per tree and we want to replicate that a wee bit (scribbles) ok and you have got 21 by 7 thats 147 trees 120 samples was too much you reckon you can handle that in a day ? 120 ?

51T: Actual samples or 120 trees ?

52C: 120 samples

53T: And you want some ? ladders so I have to move them around all day ?? might be a bit tricky mightn't it ?

54C: Trouble is if we go much below 10 trees I think it's quite important to get this variation within a tree it may turn out that varieties don't vary very much they may but because this is the preliminary we really have to look at all aspects of variation // mmh it may be that it is a product of, that there is nothing happening within a tree and next time you only need to take one sample from a tree
T: Mmh

55T: (=) I don't know that its gonna matter much if it takes a couple of days because when all the larvae are all there as in or at the end of winter time and there overwinter there that wont be diapause // but they all stay relatively the same age and things so it shouldnt matter too much
C: Right

56C: Oh that's allright then yeah ok we might increase that then

(Laughter)

57T: Well we do every tree

58C: Be ideal wouldn't it, ehm, how will we if we make that 12 //14 sorry 7 we get two for each row //ehm there again there may be effects across here because thats the sunny side thats the southerly side // ehm so if we get 2 for each row and we can randomly allocate them within each row // so we take about 14 then you looking at 140 168 mmh yeah 168 samples // ehm which is probably not unreasonable (%) and in this way we are ? for all possible variations // except you might say its a wee bit extensive for a preliminary trial but you want to be able to know were these variations are so that in your subsequent sample you dont necessarily need to look at these and it might even turn out that perhaps 2 of these varieties are very similar ehm but these two are different well next time you only need to sample from that lot and that and that

T: Emmmh

T: Mmmh

T: Yeah

T: Mmh

T: Mmmh

T: Aha

59T: Mmmh it does seem a lot for a preliminary

60C: Mmh still you are only counting each one of your samples as a, yes, or no so in fact, if you get your sample out of the bag and you see a larvae on it you don't have to ? with a microscope // you know em you haven't thought of possibly doing some because these clusters will be approximately the same size you take leaf clusters // you could almost do density count by just counting the actual number on each one

T: yes that's right

T: Mmmh

61T: Yes ehm could do (laughs) yeah I suppose that would not be silly because its only just having one // say one in 20 // so yeah, thats probably would be a good idea

C: Mmh

C: Yeah thats right

62C: So you could actually count, you have stripped them, you've got them in the lab ehm

63T: You may as well I suppose

64C: The only thing is, that you have to standardize, is the sampling hypothesis you take // should be as similar as they can be so that you are not getting changes in numbers being a product of taking more leaves, right, because you are assuming that any sample you take from here is the same you take from anywhere // so it might be quite a good idea actually // em this is getting bigger and bigger, so you probably find if you oh if you have technicians you can charge round there in a day and it probably woudn't take you more than a day to run through those you thought they might be a few millimeters

T: Mmh

T: Yeah

T: Yeah

65T: Mmh they are fairly tiny

66C: Mmh

67T: Your ??????

68C: I don't know

(laughter)

Mmh no we better stick with that one I can't see how we could reduce that perhaps we could reduce this and then go across every second row that would be reasonable so we take 4 instead of 7 that would work because the thing has to be manageable obviously // and it ?? down to 96 now and you can do a total count on them now em does that seem reasonable

T: Mmh

69T: Yes that seems fairly allright

70C: So if you take the full(? or four) rows the outside ones cause they not gonna have unusual effects 2 in the middle effectively and then 1 from there as well // so we have ? of these so you take 2 from each row so what we'll do assume its a ? scale and this is sort of x centimeters and we just generate two random numbers that will give you the distance from there to there // two random numbers between
T: ok
T: Right

71T: (=)? random numbers with that number of trees enough // you got them
C: You have 21 is it equidistant through here

72T: Yeap

73C: Yeah so its 21

74T: Ah I see so

75C: With the random numbers we go to the random number table and look at the numbers between 1 and bound by 21 and then you can go that spacing along and do it again and go that spacing along and that spacing is from the end so if you get sort of 20 you might get 19 the first time next time you get 8 // so you really sample within each row were each with each of these designated rows // 1 2 3 4 in each of those you take 2 at random intervals from the beginning and you do that for all four of them // ehhhm I we just about covered everything when you come to your tree how tall did you say these trees were about ?
T: Mmh
T: Mmmh
T: Mmmh

76T: Yeah

77C: So getting to the top could be practically quite difficult could it ?

78T: Oh no people get up there and thin and pick

79C: Right yeah, obviously as you as you go through your sampling you develop your way of doing that but I think if you sample left and right now it be quite important to record which side that is

80T: Yeah

81C: So however the group goes say its east or west // and then you have to write that label all your bags properly just it might turn out that there are some unusual effect here because this is on the eastern side eh which catches ?? all the eastern inside so it gotta be you have ? that properly so you carried variety row eh side which is effectively position on on the track that will be counted 1 2 3 row row 1 2 3 or 4 and your variety 1 to 4
T: Mmh

82T: Looks complicated doesn't it

83C: Mmmh, are you in a hurry ? now if you you work on the principle, actually the easier way to mark these if you know ? direction you take the right side and the next one just as long as you consider ?? through // get the count on all those and then we just do a nice tricky analysis of variance on it and it all will be revealed
T: Mmmh

84T: ?????

85C: Yeah

86T: Oh yeha

87C: And if you got much more to talk about tonight

88T: Ah I think thats basically it actually

89C: You have to carefully work the size of your clusters before you get in there

90T: Yeah

91C: So that they are consistent and you know these are apples aren't they ?

92T: Yeah

93C: I don't quite know how to come down but you might get a bunch of leaves effectively // which quite clearly ? // so that you are taking the same type of thing the whole time
T: Yeah
T: Yeha

94T: Or I could perhaps oh no grade the cluster I couldn't really take some leaves off could I ?

95C: Then you have to ? for that one probably be easier // if you ? cluster from the appropriate area on the tree // just take one there is gonna be some variation its invariably random ehm and as long as its not too large you know you standardize as well as you can that should be allright
T: Yeah
T: Yeah

96T: Mmhh oh yeah ok thats sounds thats sound like all i am having a good time
(Laughter)
97T: Now I just have to do it well ???

Appendix 10b - Example of micro and macro analysis of interaction

Adjacency pair no	Control Rye	Control Paddy	Type of Statement Rye	Type of Statement Paddy
1	T	T	S	S
2/3	C	C	Q/A	Q/A
4/5	C	C	Q/A	Q/A
6/7	C	C	Q/A	Q/A
8/9	C	C	Q/A	Q/A
10/11	C	C	Q/A	Q/A
12/13	C	T	Q/A	Q/A
14/15	C	C	Q/A	Q/A
16/17	C	C	Q/A	Q/A
18/19	T	T	S/S	Q/A
20/21	C	C	Q/A	Q/A
22/23	T	T	Q/A	S/S
24/25	C	C	Q/A	Q/A
26/27	C	C	Q/A	Q/A
28/29	C	C	Q/A	S/S
30/31	C	C	S/S	S/S
32/33	C	C	S/Q/A	S/Q/A
34/35	C	C	S/S	S/S
36/37	C	C	S/S	S/Q/A
38/39	C	T	S/S	S/S
40/41	C	T	S/S	S/S
42/43	C	C	S/S	S/S
44/45	C	T	S/S	S/S
46/47	C	C	Q/A	Q/A
48/49	C	C	S/S	S/S
50/51	C	C	S/S	S/S
52/53	T	T	S/Q	S/Q
54/55	C	C	S/S	S/S
56/57	C	C	S/S	S/S
58/59	T	T	S/S	S/S
60/61	C	C	S/S	S/S
62/63	C	C	S/S	S/S
64/65	C	C	S/S	S/S
66/67	T	T	S/S	S/S
68/69	C	C	S/S	S/S
70/71	C	C	S/S	S/S
71b/72	C	C	S/S	S/S
73/74	C	C	S/S	S/S
75/76	C	T	Q/S	Q/S
79/80	C	C	S/S	S/S
81/82	C	C	S/S	S/S
83/84	C	C	Q/S/S	Q/S/S
85/86	C	T	S/S	S/S
87/88	C	C	Q/A	Q/A
89/90	C	C	S/S	S/S
91/92	C	C	Q/A	S/S
93/94	C	C	S/S	S/S
95/95c/d	C	C	S/S	S/S
96/97	T	T	S/S	S/S

T=Entomologist C=Statistician Q=Question S=Statement A=Answer

Appendix 10c - Subdivision of interaction into episodes and sub-episodes by observer

Utterance Number	Episode	Macro Structure
1	Problem Statement	
2-5	Problem Clarification	
6-7	Orchard Information	
8-9	Insect Information	Information Collection
10-13	Sampling Information	
14-23	Problem Clarification	
24-25	Historical Information	
26-27	Orchard Information	
28-31	Rough Sampling Plan	Advice Giving
32-35	Resource Information	
36-41	Sampling Information	Information Collection
42-45	Orchard Information	
46-47	Insect Information	
48-49	Rough Sampling Plan	
50-53	How many to sample	
54-57	Sample Number ok with Time	
58-59	Review Sampling Plan	Advice Giving
60-61	Check with Resources	
62-63	Re-assess Sampling Method	
64-65	General Statistics	
66-67	Insect Information	Information Collection
68-74	Actual Sampling Plan	
75-76	Random Number Selection	Advice Giving
77-78	Orchard Information	Information Collection
79-86	Sampling Methodology Advice	Advice Giving
87-88	Prepare Closing	Closing
89-95	Sampling Unit Advise	Advice
96-97	Closing	Closing

Appendix 10d - Subdivision of interaction into episodes and sub-episodes by participant

Utterance Number	Episode	Macro Structure
1	Introducing subject	
2-9	Getting basic ideas cleaned up	Initial introduction
10-23	More details about sampling	
24-27	Chris getting things straightened	More general introduction
30-31	Starting to think about experimental design	Introduction to experiment
32-35	Numbers of clusters to take	
36-45	How to take them	
46-49	Where to take them from	
50-52	Working out preliminary design	Working out basics of design
53-56	Feasibility of taking that no. of clusters	
57-58	Altering design	
59-63	Discussing reasons behind no. to take	
64-69	Practicality of the nos. to be taken	Sorting out problems and solution in design
70-76	Working out which trees to sample	
77-82	Deciding where to sample from tree	
83-84	How to analyse	
85-88	Asking if I want anything else	Finishing points
89-95	Fine points of sampling	
96-97	Finish	Finish

Appendix 11 - files that comprise the system

Filename	Language	Functions
Prelim.pro	Prolog	Overall handler, preliminary sampling
Datain.pro	Prolog	Datainput
Stats.pro	Prolog	Statistics
Myglobal.pro	Prolog	Global declarations
Grapdecl.pro	Prolog	Graphics declarations
Mtoolpre.pro	Prolog	Tools
Main1.pro	Prolog	Main sampling advice 1
Main2.pro	Prolog	Main sampling advice 2
Mytotest.pro	Prolog	Tools for Main1.pro and Main2.pro
Myglotes.pro	Prolog	Global declarations for Main1.pro and Main2.pro
Graph8.pas	Pascal	Graphics interface
Myglobal.pas	Pascal	Global delarations for graphics interface
Mygraphs.pas	Pascal	Graphics declarations for graphics interface
Mycultiv.pas	Pascal	Between-tree decisions
Mytrees.pas	Pascal	Displays selected trees
Ftable.dat	Text	Statistics table
Bgiobj.exe		Graphics drivers

Appendix 12 - Materials used in the entomology survey

Dear Colleague,

I am writing to you to ask for your assistance in my research project (use of expert systems technology for the design of insect sampling plan). The system is being designed for use by entomologists (the user) and I want to ensure maximum user-friendliness. This involves for instance using language that is familiar to the user.

I am therefore asking you to answer the two questions overleaf; which deal with the problem of how an entomologist describes the layout of an orchard to another entomologist or statistician. It is important that you answer the first question first.

Your cooperation in this survey would be very much appreciated. Please return the filled-in questionnaire to my pigeon-hole at your earliest convenience.

Greetings

Question 1: Please describe an orchard's layout/ structure (real or imaginary) in whatever way you feel most comfortable e.g., words, diagrams etc.

Question 2: Below is the diagrammatic representation of an orchard. Please describe in detail all important features of the orchard's structure.